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Fig. 8



Fig. 7



Chain-man



Offset Man



Fig. 6.



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Survey

A
MANUAL

SURVEYING FOR INDIA,

DETAILING THE MODE OF OPERATIONS

ON THE

REVENUE SURVEYS

In Bengal and the North-Western Provinces.

PREPARED FOR THE USE
OF THE
SURVEY DEPARTMENT

AND

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TO
THE HONORABLE JAMES THOMASON,
LIEUTENANT GOVERNOR
OF THE NORTH-WESTERN PROVINCES,
THIS MANUAL
IS, WITH PERMISSION,
RESPECTFULLY DEDICATED
BY HIS OBEДИENT HUMBLE SERVANTS,

THE EDITORS.

PREFACE.

It must have been apparent to the numerous Officers of the Army as well as to the various other persons appointed to the Revenue Surveys in Indiā, that scarcely one of the many English works on Geodesy extant, touch on, or afford any practical insight into, the system of Survey as carried on, and as peculiarly applicable to this country. Valuable and of high order as many of these works are, and of great importance as fixing the leading and fundamental principles of the profession, they are destitute of the most essential parts of an Indian Surveyor's duty, and of the most useful details, for adapting such principles to the nature of the country with which he has to contend.

A Surveyor of even some experience, when placed in situations of difficulty and responsibility so common in the almost boundless fields still left unexplored in this vast country, with no competent adviser at hand, and far removed from all chances of assistance, may, and often does feel greatly at a loss ; the want of

some such work therefore, as the present, forming a concise Manual, adapted to the peculiar requirements of this country, and condensing into a small space, not only what alone can be found in a vast number of standard and expensive works, but embodying the precise Modus Operandi of the Department from unpublished and exclusive sources, appears now to be called for ; and it is hoped, that in the absence of any other similar publication, which the Editors have long most anxiously looked for, from abler hands, the present attempt may not be altogether out of place.

The great extension of Surveys in India of late years, and the annexure of another large Province to the British Dominions, giving rise to the immediate necessity for a Survey and Assessment, has opened a wide field for the practical employment of Surveyors of all descriptions, both European and Native. In a Department therefore which demands a certain amount of qualification (the test for which will be found in the Appendix) it is highly desirable that previous study and fitness should form the pretensions of persons enlisting in its service. The establishment likewise of a Civil Engineering College at Roorkee, in the North Western Provinces, by His Honor the Lieutenant Governor, for the training of youths of this country, as well as of European Non-Commissioned

Officers and Privates of the Army, in the several branches of practical science, has given an additional impetus to the undertaking, and the compilation now offered to the public has been prepared with these views, as well as for practical men generally.

The arrangement of the work is consequently in the first two parts elementary, the materials for which have, of necessity, been for the most part extracted from various Authorities, chiefly from the well-known and most useful works of Mr. Simms, the Civil Engineer, and late Consulting Engineer to the Government of India, "On Mathematical Instruments" and "On Levelling". From Heather's "Treatise on Mathematical Instruments", "Jackson's" and "Frome's Surveying," "Adam's Geographical Essays," &c. &c., full extracts have been also made, and the acknowledgments of the Compilers are here duly recorded for the same, as well as to those authors from whose works extracts have been made as quoted in the Text. In the remaining Parts of the Book, it has been the aim, to render the information generally useful, not only to the Professional Surveyor, but to the Traveller and the Explorer of neighbouring countries, the Quarter Master General's Department, and for Revenue Officers, and Civil Authorities of Districts, where professional assis-

tance cannot be obtained, and every Collector must be his own Surveyor.

Through the liberal and kind assistance of Lieut. Colonel Waugh, Surveyor General of India, in placing the records of his office at their disposal, the Editors have enjoyed great advantages, of which they have not failed to avail themselves to the fullest extent, for this as well as for much valuable advice, their thanks are eminently due, and most cordially offered.

In Parts III. and V. the Compilers have been very largely assisted by Babu Radhanath Sickdhar, the distinguished head of the Computing Department of the Great Trigonometrical Survey of India, a gentleman whose intimate acquaintance with the rigorous forms and mode of procedure adopted on the Great Trigonometrical Survey of India, and great acquirements and knowledge of scientific subjects generally, render his aid particularly valuable. The Chapters 15 and 17 up to 21, inclusive, and 26 of Part III. and the whole of Part V. are entirely his own, and it would be difficult for the Compilers to express with sufficient force, the obligations they thus feel under to him, not only for the portion of the work which they desire thus publicly to acknowledge, but for the advice so generally afforded on all subjects connected with his own department.

In the Typographical appearance of the work neither expense or trouble has been spared, and it is hoped that the Diagrams and Plates drawn on Stone, and struck off separately after the printing of the text, will be at least equal in clearness and precision to the wood cuts of an English volume. The employment of two distinct presses has of course caused infinite trouble and delay, but the art of wood cutting in Calcutta, is still almost unknown, and it was therefore hopeless to carry out the design by any other means than those adopted. In the correction of the Press the utmost pains have been taken, and although the Errata in the first few pages are more numerous than could be desired, the latter part of the work will, it is believed, be found as correct as it is possible to print such difficult matter in this country. Most of the computations have been re-worked after the figures were in print, and every proof has had five or six readings.

The preparation of the work has been carried on under a press of engagements, and merely at moments of leisure after other arduous duties of the day had been attended to, which has caused the time of its publication to be very much protracted. That it contains many defects, the compilers are fully sensible of—there is much which in the arrangement and the matter

they would willingly alter if in their power. They only desire to remind their readers, that the space devoted to certain subjects precluded the possibility of entering into them more fully; in some single Chapters are condensed, what might with ease be extended into a volume. It is not professed to treat of the higher branches of Geodesy, for instance,—the Measurement of Base Lines, by Compensation Bars,—the Treatment of observed angles according to the Theory of minimum squares, so as to satisfy the Geometrical conditions of the figures to which they may appertain,—or all the refinements necessary to carry out an important Trigonometrical Survey, such as that now in progress in this country. The object has been to include so much merely, as may *be useful and necessary for ordinary Topographical or Revenue Surveyors*, and if the materials thus thrown together have the effect of maintaining a high standard of accuracy in whatever Survey operations may be undertaken, to keep pace with the refinements of the present day, and to the benefit and extension of our geographical knowledge, the labor expended in passing such a volume through the Press, will be most amply repaid.

MANUAL
 OF
SURVEYING FOR INDIA,
 Detailing the Mode of Operations
 ON THE
Revenue Surveys in Bengal and the North-West
Provinces.

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*I have written on how to use the instrument
 to obtain the grade of the 4 Kent. Survey.
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 of the manual of surveying*

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A
MANUAL OF SURVEYING

FOR

I N D I A.

Part II.

G E O M E T R Y.

CHAPTER I.

NECESSARY DEFINITIONS AND FIRST PRINCIPLES.

Read
GEOMETRY is the science that treats of the properties of magnitude in general. The subjects which it considers are extent of distance, extent of surface, and extent of capacity or solid content. It is the foundation of Mensuration, Surveying and other practical branches: it embraces the measurement equally of the earth and the heavens; it forms with arithmetic the basis of all accurate conclusions in the mixed sciences, and there is scarcely any mechanical art, our views of which may not be improved by an acquaintance with it.

The truths of Geometry are founded on definitions, each furnishing at once an exact notion of the thing defined, and the groundwork of all conclusions relating to it. The leading definitions are as follows:—

A point is that which has position but not magnitude.

A line is length without breadth.

COROLLARY.—The extremities of a line are points; and the intersections of one line with another are also points.

If two lines are such that they cannot coincide in any two points, without coinciding altogether, each of them is called a straight line.

COROLLARY.—Hence two straight lines cannot enclose a space. Neither can two straight lines have a common segment; for they cannot coincide in part, without coinciding altogether.

A superficies is that which has only length and breadth.

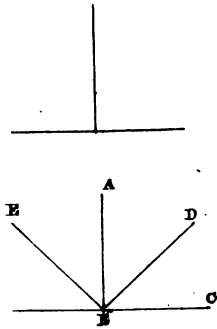
COROLLARY.—The extremities of a superficies are lines; and the intersections of one superficies with another are also lines.

A plane superficies is that in which any two points being taken, the straight line between them lies wholly in that superficies.

A plane rectilineal angle is the inclination of two straight lines to one another, which meet together, but are not in the same straight line.*

When a straight line standing upon another straight line makes the adjacent angles equal to one another, each of them is called a *right angle*, and the straight line which stands upon the other is called a *perpendicular* to it.

If an angle is not *right* it is called *oblique*. An oblique angle is said to be *acute* or *obtuse* according as it is less or greater than a right angle. Thus: ABC is a right angle, DBC an acute angle, and EBC an obtuse angle.



* When several angles are at one point B, any one of them is expressed by three letters, of which the letter that is at the vertex of the angle, that is, at the point in which the straight lines that contain the angle meet one another, is put between the other two letters, and one of these two is somewhere upon one of those straight lines, and the other upon the other line. Thus the angle which is contained by the straight lines AB, CB is named the angle ABC, or CBA; that which is contained by AB, BD is named the angle ABD or DBA, and that which is contained by DB, CB is called the angle DBC or CBD, but if there be only one angle at a point it may be expressed by a letter placed at that point.

A figure is that which is enclosed by one or more boundaries. The space contained within a figure is called the *Area* of the figure.

A *plane triangle* is a figure bounded by three right lines.

A triangle is said to be *right-angled* when it has a right angle. Of triangles which are not right-angled, and which are therefore said to be *oblique-angled*, an *obtuse-angled* triangle, is that which has an obtuse angle, and an *acute-angled* triangle is that which has three acute angles, Thus :

A is a right-angled triangle.

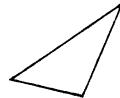
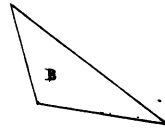
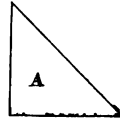
B an obtuse-angled triangle.

C an acute-angled triangle.

An *Equilateral* triangle is that which has all three sides equal.

An *Isosceles* triangle is that which has only two sides equal.

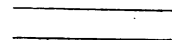
A *Scalene* triangle is that which has all its sides unequal.



The three sides of any the same triangle are frequently distinguished by giving to one of them the name of *base*, in which case the other two are called *the two sides*, and the angular point opposite to the base is called the *vertex*.

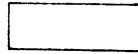
In a right-angled triangle, the side which is opposite to the right angle is called the *hypotenuse*; and of the other two sides, one is frequently termed the *base*, and the other the *perpendicular*.

Parallel lines are those which have no inclination towards each other, and are every where equi-distant.

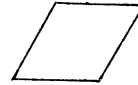


All Plane figures bounded by four sides are called quadrangles or quadrilaterals.

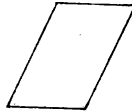
A *Parallelogram* is a quadrangle which has its opposite sides parallel.



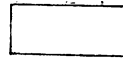
A *Rhombus* is a quadrangle which has all its sides equal, but its angles are not right angles.



A *Rhomboid* is a quadrangle which has its opposite sides equal to one another, but all its sides are not equal, nor its angles right angles.



A *Rectangle* is a quadrangle which has a right angle.



A *Square* is a rectangle which has two adjoining sides equal.



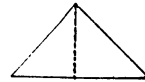
All other four-sided figures are called *Trapeziums*, and all figures containing more than four sides are called *Polygons*.



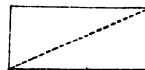
A *Regular Polygon* is that whose angles and sides are all equal.



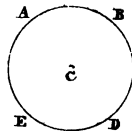
The *Altitude* of a parallelogram or triangle, is a perpendicular drawn to the base from the angle opposite.



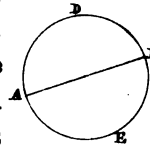
The *Diagonals* of a quadrilateral are the straight lines which join its opposite angles.



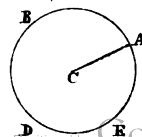
A *Circle* is a plane figure bounded by a curved line called the *Circumference*, every part whereof is equally distant from a point within the same figure called the *Centre*, thus: ABDE is the *circumference* and C the *centre*.



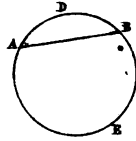
The *Diameter* of a circle is a straight line drawn through the centre, and terminated both ways by the circumference, thus: AB is the *diameter* of the circle ADBE.



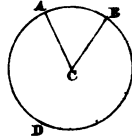
The *Radius* of a circle is a straight line drawn from the centre to the circumference, thus: CA is the *radius* of the circle ABDE.



A *Segment* of a circle is the figure contained by a straight line and the portion of the circumference it cuts off, thus: ABD is a *segment* of the circle AEDB.



A *Sector* of a circle is any part bounded by an arc and two radii to its extremities, thus: ACB is a *sector* of the circle BAD.



The circumference of every circle is supposed to be divided off into 360 equal parts, called *degrees*, each degree is subdivided into 60 equal parts, called *minutes*, and each minute into 60 equal parts, called *seconds*. Degrees are expressed thus: ° minutes, thus: ' seconds, thus: "

A *Quadrant* of a circle will therefore contain 90 degrees, and a *Semicircle* 180 degrees.

The *Measure* of every plane angle is an arc of a circle, whose centre is the angular point, and is said to be of so many *degrees*, *minutes* and *seconds*, as are contained in its measuring arc.

The *Complement* of an arc or angle, is what it wants of a right angle or 90 degrees.

The *Supplement* of an arc or angle, is what it wants of two right angles or 180 degrees.

The *Magnitudes* of arcs or angles, are determined by certain straight lines, appertaining to a circle, called *Chords*, *Sines*, *Tangents* and *Secants*.

The *Chord* of an arc is a straight line, joining its extreme points.

The *Sine* of an arc is a line drawn from either end of it, perpendicular to a diameter meeting the other end.

The *Tangent* of an arc is a line proceeding from either end, perpendicular to the radius joining it; the length of which is limited by a line drawn from the centre through the other end.

The *Secant* of an arc is the line proceeding from the centre, and limiting the tangent of the same arc.

The *Versed Sine* of an arc is that part of the diameter intercepted between the sine and the end of the said arc.

The *Co-Sine*, *Co-Tangent*, etc., of any arc is the *Sine*, *Tangent*, etc., of its complement. Thus :

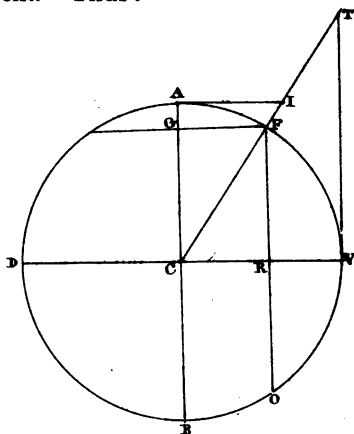
FO, is the *Chord* of the arc FVO.

FR, is the *Sine* of the arcs VF and FAD.

VT, is the *Tangent* of the arc FV.

CT, is the *Secant* of the arc FV.

RV, RD, are the *Versed Sines* of the arcs, FV, and FAD.



FG is the *Co-Sine*, AI the *Co-Tangent*, and CI the *Co-Secant* of the arc FV.

The *Chord* of 60° , the *Sine* of 90° , the *Versed-Sine* of 90° , the *Tangent* of 45° , and the *Secant* of 0° are all equal to the radius.

It is obvious that in making use of these lines, the same radius must always be used, otherwise there would be no settled proportions between them.

A *Theorem* is a proposition, wherein something is proposed to be demonstrated.

A *Problem* is a proposition, wherein something is to be done or effected.

A *Lemma* is some demonstration, previous and necessary, to render what follows the more easy.

A *Corollary* is a consequent truth, which follows immediately from some preceding truth or demonstration.

A *Scholium* is a remark or observation.

An *Axiom* is a proposition, which is assumed to be true, without demonstration.

A *Postulate* is something, which is assumed as possible to be done, without demonstrating how it is to be done.

AXIOMS.

1. Things which are equal to the same thing, are equal to one another.
2. If equals be added to equals, the wholes are equal.
3. If equals be taken from equals, the remainders are equal.
4. If equals be added to unequals, the wholes are equals.
5. If equals be taken from unequals, the remainders are unequals.
6. Things which are double of the same, are equal to one another.
7. Things which are halves of the same, are equal to one another.
8. Magnitudes which coincide with one another, that is, which exactly fill the same space, are equal to one another.
9. The whole is greater than its part.
10. All right angles are equal to one another.

POSTULATES.

1. That a right line may be drawn from any one given point to another.
2. That a right line may be produced or continued at pleasure.
3. That from any centre and with any radius the circumference of a circle may be described.
4. It is also required, that the equality of lines and angles to others given, be granted as possible : That it is possible for one right line to be perpendicular to another, at a given point or distance ; and that every magnitude has its half, third, fourth, &c., part.

SIGNS.

The Sign = denotes the quantities between which it stands to be equal.

The Sign + denotes the quantity it precedes to be added.

The Sign — denotes the quantity which it precedes to be subtracted.

The Sign \times denotes the quantities between them to be multiplied into each other.

The Sign \div stands for division.

The Sign $>$ greater than.

The Sign $<$ less than.

The Sign ∞ Difference between.

To denote that four quantities, A, B, C, D, are proportional, they are usually written thus: $A : B :: C : D$, and read thus: A is to B, so is C to D; but when three quantities, A, B, C, are proportional, the middle quantity is repeated, and they are written $A : B :: B : C$.

CHAPTER II.

PRACTICAL GEOMETRY.

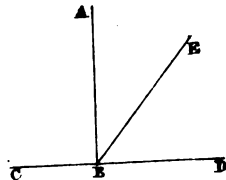
GEOMETRICAL THEOREMS.

THEOREM I.

If a right line falls on another, as AB, or EB does on CD, it either makes with it two right angles, or two angles equal to two right angles.

1. If AB be perpendicular to CD, then the angles CBA and ABD, will be each a right angle.

2. But if EB fall obliquely on CD, then will the angles DBE + EBC = DBE + EBA (= DBA) + ABC, or to two right angles. Q. E. D.



Corollary 1. If any number of right lines are drawn from one point on the same side of a right line; all the angles made by these lines will be equal to two right angles.

Cor. 2. All the angles which can be made about a point, will be equal to four right angles.

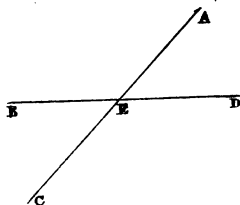
THEO. II.

If one right line crosses another, as AC does BD , the opposite angles, made by those lines, will be equal to each other, that is AEB to CED and BEC to AED .

By Theorem I. $BEC + CED = 2$ right angles, and $CED + DEA = 2$ right angles.

Therefore (by Axiom 1.) $BEC + CED = CED + DEA$, take CED from both, and there remains $BEC = DEA$. (by Axiom 3.)

In the same manner $CED + AED = 2$ right angles; and $AED + AEB = 2$ right angles: wherefore taking AED from both, there remains $CED = AEB$. Q. E. D.



THEO. III.

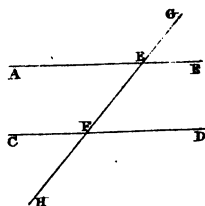
If a right line crosses two parallel lines as GH does AB and CD then,

1st. The sum of the interior angles on the same side will be equal to two right angles, that is $AEF + CFE$ equal to two right angles and $BEF + DFE$ equal to two right angles.

2nd. The alternate angles will be equal, that is $AEF = EFD$ and $BEF = CFE$.

3rd. The exterior angle will be equal to the interior and opposite one on the same side, that is $AEG = CFE$ and $BEG = DFE$.

1st. If the angles AEF and CFE be not equal to two right angles, let them, if possible, be greater than two right angles;—then because the lines AE and CF are not more parallel than EB and FD , the angles BEF and DFE are also greater than two right angles. Therefore the four angles AEF , CFE , BEF , DFE are greater than four right angles and (by Theorem I.) they are also equal to four right angles which is absurd.



In the same manner it may be shown that the angles AEF and CFE cannot be less than two right angles. Therefore

they are equal to two right angles. Wherefore also the angles BEF and DFE are equal to two right angles.

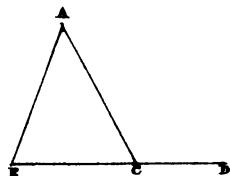
2nd. Now $\text{AEF} + \text{CFE} = \text{two right angles}$. Again (by Theorem I.) $\text{CFE} + \text{DFE} = \text{two right angles}$. Therefore (by Axiom 1) $\text{AEF} + \text{CFE} = \text{CFE} + \text{DFE}$. Take away CFE from both and there remains $\text{AEF} = \text{DFE}$ (by Axiom 3). In the same manner we prove that $\text{BEF} = \text{CFE}$.

3rd. Now $\text{BEF} = \text{CFE}$, and (by Theorem II.) $\text{BEF} = \text{AEG}$. Therefore $\text{AEG} = \text{CFE}$ (by Axiom 1.) In the same way we prove $\text{BEG} = \text{DFE}$. Q. E. D.

THEO. IV.

If in any triangle ABC, one of its sides as BC is produced towards D, it will make the external angle ACD equal to the two internal opposite angles taken together; viz. to B and A.

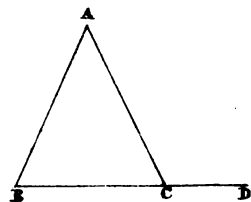
Through C let CE be drawn parallel to AB; then since BD cuts the two parallel lines, BA, CE; the angle $\text{ECD} = \text{B}$, (by part 3 of the last Theo.) and again, since AC cuts the same parallels, the angle $\text{ACE} = \text{A}$ (by part 2 of the last Theo.) Therefore $\text{ECD} + \text{ACE} = \text{ACD} = \text{B} + \text{A}$. Q. E. D.



THEO. V.

In any triangle ABC, all the three angles taken together are equal to two right angles, viz. $\text{A} + \text{B} + \text{ACB} = \text{two right angles}$.

Produce BC to any distance as D, then (by the last Theo.) $\text{ACD} = \text{B} + \text{A}$; to both add ACB; then $\text{ACD} + \text{ACB} = \text{A} + \text{B} + \text{ACB}$: But $\text{ACD} + \text{ACB} = 2 \text{ right angles}$ (by Theo. I.), therefore the three angles $\text{A} + \text{B} + \text{ACB} = 2 \text{ right angles}$. Q. E. D.



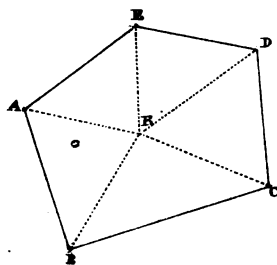
Cor. 1. If one angle of a triangle be known, the sum of the other two is also known: For since the three angles

of every triangle contain two right angles or 180 degrees, therefore 180 less the given angle will be equal to the sum of the other two; or 180 less the sum of two given angles, gives the other one.

Cor. 2. In every right-angled triangle, the two acute angles = 90 degrees, or one right angle: Therefore 90 degrees less one acute angle, gives the other angle.

Cor. 3. All the interior angles of any rectilinear figure, together with four right angles, are equal to twice as many right angles as the figure has sides.

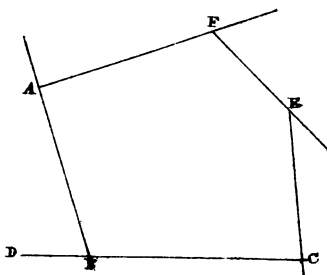
For any rectilinear figure ABCDE, can be divided into as many triangles as the figure has sides, by drawing straight lines from a point F within the figure to each of its angles. And, by this Theorem, all the angles of these triangles are equal to



twice as many right angles as there are triangles, that is, as there are sides of the figure: and the same angles are equal to the angles of the figure, together with the angles at the point F, which is the common vertex of the triangles; that is, together with four right angles. Therefore all the angles of the figure, together with four right angles, are equal to twice as many right angles as the figure has sides.

Cor. 4. All the exterior angles of any rectilinear figure are together equal to four right angles.

Because every interior angle ABC, with its adjacent exterior ABD, is equal to two right angles; therefore all the interior, together with all the exterior angles of the figure, are equal to twice as many right angles as there are sides of the figure;

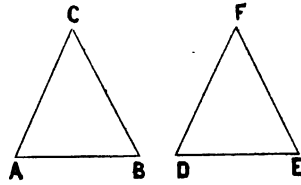


that is, by the foregoing corollary, they are equal to all the interior angles of the figure, together with four right angles; therefore all the exterior angles are equal to four right angles.

THEO. VI.

If in any two triangles, ABC , DEF , there be two sides, AB , AC , in the one, severally equal to two sides, DE , DF , in the other, and the angle A contained between the two sides in the one, equal to the angle D in the other; then the remaining angles of the one, will be severally equal to those of the other, viz: $B = E$ and $C = F$; and the base of the one, BC , will be equal to EF , that of the other.

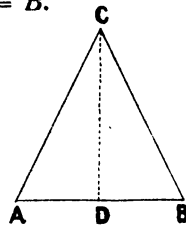
If the triangle ABC be supposed to be laid on the triangle DEF , so as to make the points A and B coincide with D and E , which they will do, because $AB = DE$; and since the angle $A = D$, the line AC will fall along DF , and inasmuch as they are supposed equal, C will fall in F ; seeing therefore the three points of one coincide with those of the other triangle, they are manifestly equal to each other; therefore the angle $B = E$ and $C = F$, and $BC = EF$. Q. E. D.



LEMMA.

If two sides of a triangle ABC be equal to each other, that is $AC = CB$; the angles which are opposite to those equal sides, will also be equal to each other, viz: $A = B$.

For let the triangle ABC be divided into two triangles CDA , CDB , by making the angle $ACD = DCB$ (by postulate 4) then because $AC = BC$ and CD common, the triangle $ADC = CDB$; and therefore the angle $A = B$. Q. E. D.

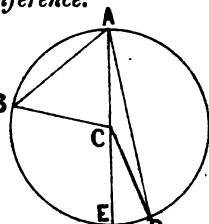


Cor. If from any point in a perpendicular which bisects a given line, there be drawn right lines, to the extremities of the given one, they with it will form an isosceles triangle.

THEO. VII.

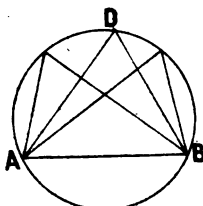
The angle BCD , at the centre of a circle $ABED$, is double the angle BAD at the circumference.

Through the point A , and the centre C , draw the line ACE : Then the angle $ECD = CAD + CDA$; (by Theo. 4) but since $AC = CD$ being radii of the same circle, it is plain (by the preceding Lemma) that the angles subtended by them, will be also equal, and that their sum is the double of either of them, that is $DAC + ADC$ is double of CAD , and therefore ECD is double of CAD ; in the same manner BCE is double of CAB , wherefore, $BCE + ECD$ or BCD is double of $BAC + CAD$ or of BAD . Q. E. D.



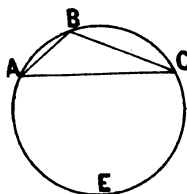
Cor. 1. An angle at the circumference is measured by half the arc it subtends or stands on.

Cor. 2. All angles at the circumference of a circle which stand on the same chord as AB , are equal to each other or they are all measured by half the arc they stand on, viz. by half the arc AB .

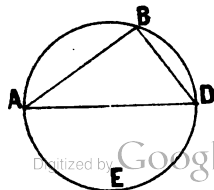


Cor. 3. An angle in a segment greater than a semi-circle is less than a right angle; thus ADB is measured by half the arc AB , but as the arc AB is less than a semi-circle, the arc AB or the angle ADB is less than half a semi-circle, and consequently less than a right angle.

Cor. 4. An angle in a segment less than a semi-circle is greater than a right angle, for since the arc AEC is greater than a semi-circle, its half, which is the measure of the angle ABC , must be greater than half a semi-circle, that is, greater than a right angle.



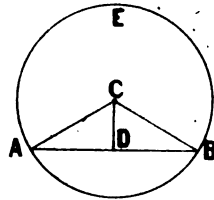
Cor. 5. An angle in a semi-circle is a right angle, for the measure of the angle ABD , is half of a semi-circle AED , and therefore a right angle.



THEO. VIII.

If from the centre C of a circle ABE, there be let fall the perpendicular CD on the chord AB, it will bisect it in the point D.

Let the lines CA and CB be drawn from the centre to the extremities of the chord, then since $CA = CB$, the angle $CAB = CBA$ (by the Lemma Theo. 6). But the triangles ADC, BDC are right-angled triangles, since the line CD is a perpendicular; therefore the angle $ACD = DCB$; (by Cor. 2. Theo. 6) then we have AC, CD, and the angle ACD in one triangle, severally equal to CB, CD, and the angle BCD in the other: Therefore (by Theo. 6). $AD = DB$. Q. E. D.

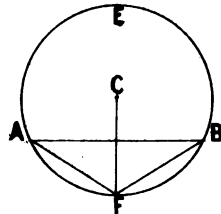


Cor. Hence it follows, that any line bisecting a chord at right angles is a diameter; for a line drawn from the centre perpendicular to a chord, bisects that chord at right angles; therefore vice versâ a line bisecting a chord at right angles must pass through the centre, and consequently be a diameter.

THEO. IX.

If from the centre of a circle ABE there be drawn a perpendicular CD on the chord AB, and produced till it meets the circle in F, that line, CF, will bisect the arc AB in the point F.

Let the lines AF and BF be drawn, then in the triangles ADF, BDF; $AD = BD$ (by the last Theo.); DF is common, and the angle $ADF = BDF$ being both right angles, for CD or DF is a perpendicular. Therefore (by Theo. 6.); $AF = FB$; but in the same circle equal lines are chords of equal arcs, since they measure them; whence the arc $AF = FB$, and so AFB is bisected in F, by the line CF.

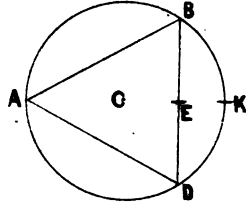


Cor. The sine of an arc is half the chord of twice that arc. For AD is the sine of the arc AF, AF is half the arc, and AD half the chord AB (by Theo. 8.)

THEO. X.

In any triangle ABD, the half of each side is the sine of the opposite angle.

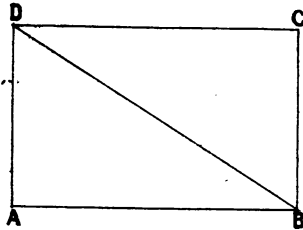
Let the circle ABD be drawn through the points A, B, D; then the angle DAB is measured by half the arc BKD, (by Cor 1. Theo. 7) viz: the chord of BK is the measure of the angle BAD; therefore (by Cor. to the last Theo.) BE the half of BD is the sine of BAD: In the same way may be proved that half of AD is the sine of ABD, and the half of AB the sine of ADB. Q. E. D.



THEO. XI.

If two equal and parallel lines AB, CD, be joined by two other lines AD, BC, those lines will be also equal and parallel.

Let the diagonal BD be drawn, and we have the two triangles ABD, CDB; whereof AB in one is equal to CD in the other, DB being common to both, and the angle $\text{ABD} = \text{CDB}$ (by Part 2. Theo. 3.); therefore (by Theo. 6.) $\text{AD} = \text{CB}$, and the angle $\text{CBD} = \text{ADB}$, consequently the lines AD and BC are parallel.



Cor. 1. The quadrilateral figure ABCD is a parallelogram, and the diagonal BD bisects the same, inasmuch as the triangle $\text{ABD} = \text{BDC}$, as now proved.

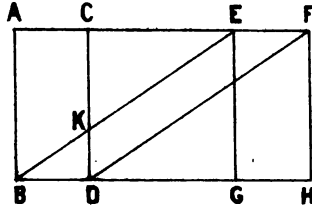
Cor. 2. The triangle ADB on the base AB, and between the same parallel with the parallelogram, ABCD, is half the parallelogram.

Cor. 3. It is also plain, that the opposite sides of a parallelogram are equal; for it has been proved that ABCD being a parallelogram, $\text{AB} = \text{CD}$ and $\text{AD} = \text{BC}$.

THEO. XII.

All parallelograms on the same or equal bases and between the same parallels are equal to one another, that is if $BD = GH$, and the lines BH and AF are parallel, then the parallelogram $ABDC = BDFE = EFGH$.

For $AC = DB = EF$ (by Cor. 3d last Theo.) to both add CE , then $AE = CF$. In the triangles ABE , CDF ; $AB = CD$ and $AE = CF$ and the angle $BAE = DCF$ (by part 3.



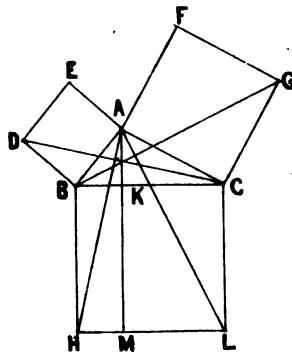
Theo. 3.); therefore the triangle $ABE = CDF$ (by Theo. 6.); let the triangle CKE be taken from both, and we have the trapezium $ABKC = KDFE$; to each of these add the triangle BKD , then the parallelogram $ABCD = BDEF$; in like manner we may prove the parallelogram $EFGH = BDEF$. Therefore $ABDC = BDEF = EFGH$. Q. E. D.

Cor. Triangles on the same or equal bases and between the same parallels, are equal, seeing (by Cor. 2. Theo. 11.) they are the halves of their respective parallelograms.

THEO. XIII.

In every right-angled triangle ABC , the square of the hypotenuse or longest side, BC , or $BCMH$, is equal to the sum or the squares made on the other two sides, AB and AC , that is, to $ABDE$ and $ACGF$.

Through A draw AKL perpendicular to the hypotenuse BC , join AH , AM , DC and BG ; in the triangles BDC , ABH , $BD = BA$ being sides of the same square, and also $BC = BH$, and the included angle $DBC = ABH$, (for $DBA = CBH$ being both right angles, to both add ABC , then DBC



= ABH), therefore the triangle $DBC = ABH$ (by Theo. 6.); but the triangle DBC is half of the square $ABDE$ (by Cor. 2. Theo. 11.) and the triangle ABH is half the parallelogram $BKLN$ (by the same Theo.); therefore half the square $ABDE$ is equal to half the parallelogram $BKLN$, and the square $ABDE$ equal to the parallelogram $BKLN$. In the same way may be proved, that the square $ACGF$, is equal to the parallelogram $KCLM$. So $ABDE + ACGF$ the sum of the squares, = $BKLN = KCLM$, the sum of the two parallelograms or square BCM ; therefore the sum of the squares on AB and AC is equal to the square on BC . Q. E. D.

Cor. 1: The hypotenuse of a right-angled triangle may be found by having the other two sides; thus, the square root of the sum of the squares of the base and perpendicular, will be the hypotenuse.

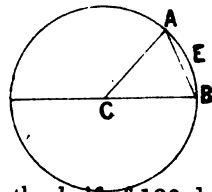
Cor. 2. Having the hypotenuse and one side given to find the other; the square root of the difference of the squares of the hypotenuse and given side will be the required side.

THEO. XIV.

In all circles the chord of 60 degrees is always equal in length to the radius.

Thus in the circle $AEBD$, if the arc AEB be an arc of 60 degrees, and the chord AB be drawn; then $AB = CB = AC$.

In the triangle ABC , the angle ACB is 60 degrees, being measured by the arc AEB ; therefore the sum of the other two angles is 120 degrees (by Cor. 1. Theo. 5.) but since $AC = CB$, the angle $CAB = CBA$ (by Lemma Theo. 6.) consequently each of them will be 60, the half of 120 degrees, and the three angles will be equal to one another, as well as the three sides: Therefore $AB = BC = AC$. Q. E. D.



THEO. XV.

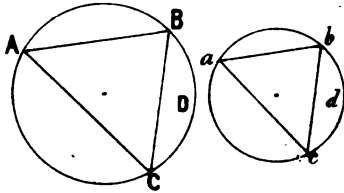
If in two triangles ABC , abc , all the angles of one, be each respectively equal to all the angles of the other, that is $A = a$, $B = b$, $C = c$: then the sides opposite to the equal angles will be proportional, viz :

$$AB : ab :: AC : ac$$

$$AB : ab :: BC : bc$$

$$\text{and } AC : ac :: BC : bc$$

For the triangles being inscribed in two circles, it is plain since the angle $A = a$, the arc $BDC = bdc$, and consequently the chord BC is to bc , as the radius of the circle ABC is to



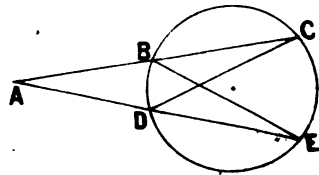
the radius of the circle abc ; (for the greater the radius is, the greater is the circle described by that radius; and consequently the greater any particular arc of that circle is, so the chord, sine, tangent, &c. of that arc will be also greater; therefore in general, the chord, sine, tangent, &c. of any arc is proportional to the radius of the circle); the same way the chord AB is to the chord ab , in the same proportion.

Therefore $AB : ab :: BC : bc$; in the same manner the rest may be proved to be proportional.

THEO. XVI.

If from a point A without a circle $DBCE$, there be drawn two lines ADE , ABC , each of them cutting the circle in two points; the product of one whole line into its external part, viz: AC into AB , will be equal to that of the other line into its external part, viz: AE into AD .

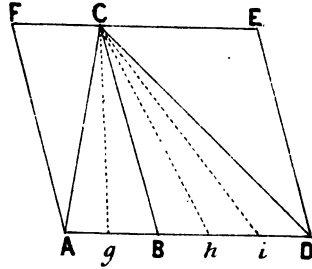
Let the lines DC , BE be drawn, in the two triangles ABE , ADC ; the angle $AEB = ACD$, (by Cor. 2. Theo. 7.) the angle A is common, and (by Cor. 1. Theo. 5.) the angle $ADC = ABE$; therefore the triangles ABE , ADC are mutually equiangular, and consequently, (by the last Theo.) $AC : AE :: AD : AB$; wherefore AC multiplied by AB , will be equal to AE multiplied by AD . Q. E. D.



THEO. XVII.

Triangles ABC, BCD, and parallelograms ABCF, BDEC having the same altitude, have the same proportion between themselves as their bases AB and BD.

Let any aliquot part of AB be taken, which will also measure BD: suppose that to be Ag, which will be contained twice in AB, and three times in BD, the parts Ag, gB, Bh, hi and iD being all equal, and let the lines gC, hC, iC be drawn:



Then (by Cor. to Theo. 12.) all the small triangles AgC, gCB, BCh, &c. will be equal to each other, and will be as many as the parts into which their bases were divided; therefore it will be, as the sum of the parts in one base, is to the sum of those in the other, so will be the sum of the small triangles in the first, to the sum of the small triangles in the second triangle; that is $AB : BD :: ABC : BDC$.

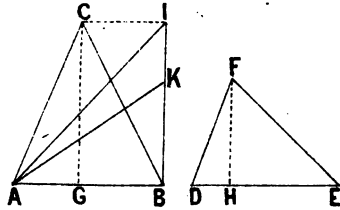
Whence also the parallelograms ABCF and BDEC being (by Cor. 2. Theo. 11.) the doubles of the triangles, are likewise as their bases. Q. E. D.

THEO. XVIII.

Triangles ABC, DEF, standing upon equal bases, AB and DE, are to each other as their altitudes CG and FH.

Let BI be perpendicular to AB and equal to CG, in which let $KB = FH$, and let AI and AK be drawn.

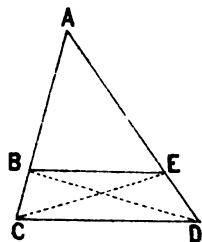
The triangle $AIB = ACB$ (by Cor. to Theo. 12.) and $AKB = DEF$; but (by Theo. 17.) $BI : BK :: ABI : ABK$. That is $CG : FH :: ABC : DEF$. Q. E. D.



THEO. XIX.

If a right line BE be drawn parallel to one side of a triangle ACD , it will cut the two other sides proportionally, viz : $AB : BC :: AE : ED$.

Draw CE and BD ; the triangles BEC and EBD being on the same base BE and under the same parallel CD , will be equal (by Cor. to Theo. 12.), therefore (by Theo. 17.) $AB : BC :: (BEA : BEC \text{ or } BEA : BED) :: AE : ED$. Q. E. D.



Cor. 1. Hence $AC : AB :: AD : AE$: for $AC : AB :: (AEC : AEB :: ABD : AEB) :: AD : AE$.

Cor. 2. It also appears that a right line, which divides two sides of a triangle proportionally, must be parallel to the remaining side.

Cor. 3. Hence also Theo. 15. is manifest: since the sides of the triangles ABE , ACD being equiangular, are proportional.

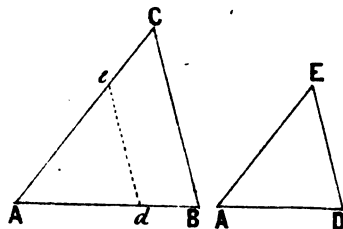
THEO. XX.

If two triangles ABC , ADE , have one angle BAC , equal to one angle DAE , and the sides about the equal angles proportional, that is $AB : AD :: AC : AE$, then the triangles will be mutually equiangular.

In AB take $Ad = AD$, and let de be parallel to BC , meeting AC in e .

Because (by the first Cor. to the foregoing Theo.) $AB : Ad :: (AD) AC : Ae$, and $AB : AD ::$

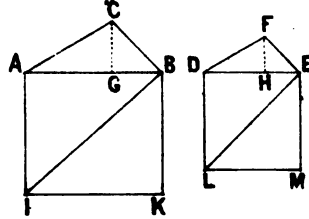
$AC : AE$; therefore $Ae = AE$ seeing AC bears the same proportion to each; and (by Theo. 6.) the triangle $Adc = ADE$, therefore the angle $Ade = D$ and $Aed = E$, but since ed and BC are parallel (by part 3. Theo. 3.) $Ade = B$, and $Aed = C$, therefore $B = D$ and $C = E$. Q. E. D.



THEO. XXI.

Equiangular triangles ABC, DEF, are to one another in a duplicate proportion of their homologous or like sides; or as the squares AK and DM of their homologous sides.

Let the perpendiculars CG and FH be drawn, as well as the diagonals BI and EL.



The perpendiculars make the triangles ACG and DFH equiangular, and therefore similar

(by Theo. 15.) for because the angle CAG = FDH and the right angle AGC = DHF, the remaining angle ACG = DFH, (by Cor. 2. Theo. 5.)

Therefore $GC : FH :: (AC : DF) :: AB : DE$, or which is the same thing $GC : AB :: FH : DE$, for FH multiplied by AB = AB multiplied by FH.

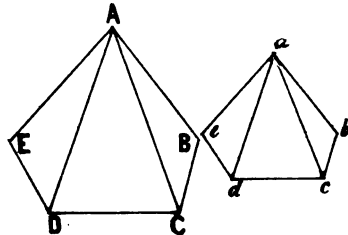
(By Theo. 18) $ABC : ABI :: (CG : AI, \text{ or } AB :: FH : DE, \text{ or } DL) :: DFE : DLE$, therefore $ABC : ABI :: DFE : DLE$, or $ABC : AK :: DFE : DM$, for AK is double the triangle ABI, and DM double the triangle DEL, (by Cor. 2. Theo. 11.)
Q. E. D.

THEO. XXII.

Like polygons ABCDE, abcde, are in a duplicate proportion to that of the sides AB, ab, which are between the equal angles A and B, and a and b, or as the squares of the sides AB, ab.

Draw AD, AC, ad, ac.

Now $AB : ab :: BC : bc$, and also the angle B = b; therefore (by Theo. 20.) $BAC = bac$; and $ACB = acb$; in like manner $EAD = ead$, and $EDA = eda$. If therefore from the



equal angles A, and a, we take the equal ones $EAD + BAC = ead + bac$, the remaining angle $DAC = dac$, and if from the equal angles D and d, $EDA = eda$ be taken, we

6. The co-sine of an arc is to radius, as radius is to the secant.

7. The sine of an arc is to radius, as the tangent is to the secant.

The triangles CLH, and CBK being similar, (by Theo. 15.)

1. $CL : LH :: CB : BK.$

2. Or, $CB : BK :: CL : LH.$

The triangles CFH, and CDI, being similar.

3. CF (or LH) : $FH :: CD : DI.$

4. $CD : DI :: CF$, (or LH) : $FH.$

The triangles CDI and CKB are similar; for the angle $CID = KCB$, being alternate ones (by part 2. Theo. 3.) the lines CB and DI being parallel: The angle $CDI = CBK$ being both right angles, and consequently the angle $DCI = CKB$, wherefore,

5. $DI : CD :: CB : BK.$

And again, making use of the similar triangles CLH, and CBK.

6. $CL : CB : CH : CK.$

7. $HL : CH : BK : CK.$

CHAPTER III.

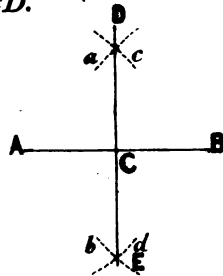
PRACTICAL GEOMETRY.

GEOMETRICAL PROBLEMS.

PROBLEM I.

To bisect a given right line AB, that is, to cut it at right angles by another right line CD.

1. From the point A as a centre, and with any radius greater than half the length of the given line, describe the arcs *a* and *b*, above and below the said line. 2. With the same radius and from B as a centre, describe the arcs *c* and *d*, intersecting the former. 3. Through the points of intersection, draw the line DE, which will divide the given line into two equal parts in the point C, as required.



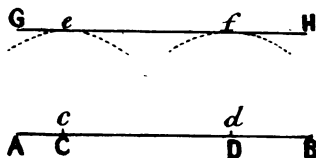
NOTE.—CD is a perpendicular raised in the middle of the line AB, therefore the four angles about the point C are right angles: also by this problem, a circle can be divided into four equal parts called Quadrants.

PROB. II.

To draw a line parallel to a given line AB.

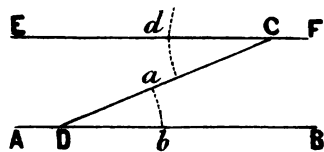
Case I. When the parallel line is to be at a given distance.

1. Take two points c and d in the given line; and from the points c and d as centres, and the given distance for a radius, describe the arcs e and f . 2. Draw the line GH , touching both arcs without cutting them, and it will be parallel to AB as required.



Case II. When the parallel line is to pass through a given point C.

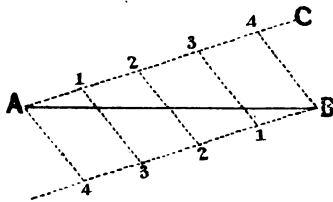
1. Take any point D , in the line AB , and draw the line DC . 2. Make the angle ECD equal to CDB , and the line EF will be parallel to AB , as required.



PROB. III.

To divide a given line AB into any number of equal parts.

1. Draw the line AC , and make an angle at B , equal to the given angle at A . 2. With any convenient distance, set off the number of parts required (suppose four) from A towards C , and also the same parts from B towards D . 3. Draw the lines $(A.4)$, (1.3) , (2.2) , (3.1) , $(4.B)$, which will divide the line AB , as required.



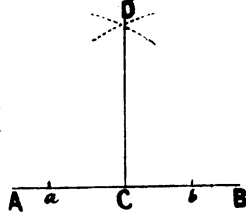
NOTE.—This operation not only divides AB , but also AC , or BD , into four equal parts.

PROB. IV.

To erect a perpendicular from a given point C in a given right line AB .

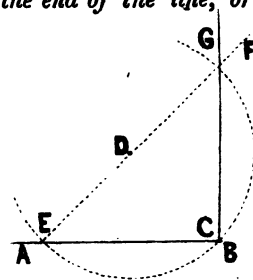
Case I. When the given point is near the middle of the line.

1. Set off two equal distances from it on the line AB , as Ca and Cb . 2. With any radius greater than aC , and from a as a centre, describe an arc. 3. With the same radius, and from b as a centre, describe another arc, cutting the former in D . 4. Draw the line CD , which will be the perpendicular to AB , as required.



Case II. When the given point C is at the end of the line, or near the end.

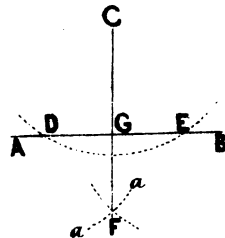
1. From any point D (not in the given line) as a centre, and with the radius DC , describe an arc, cutting AB in E and C . 2. Draw the line EF through the point D , cutting the arc in F . 3. Through the point of intersection F , draw the line CG , which will be the perpendicular required.



PROB. V.

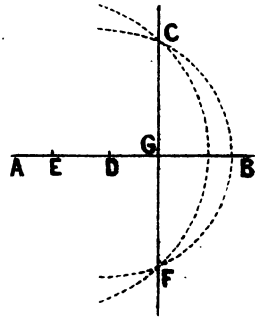
To let fall a perpendicular from a given point C , on a given right line AB .

1. From C as a centre, describe an arc cutting the given line in two places, D and E . 2. From D as a centre, and a radius longer than DG , describe the arc aa : and with the same radius, and from E as a centre, describe another arc cutting the first in F . 3. Draw the line CF , and CG is the perpendicular required.



When the given point C is nearly opposite the end of the line.

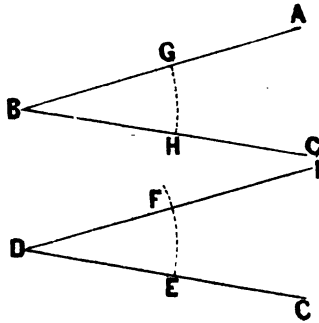
1. Take any two points D and E, in the given line, and from D, with the radius DC, describe an arc. 2. From E, with the radius EC, describe another arc; then through the points of intersection C and F, draw a line and CG will be the perpendicular required.



PROB. VI.

To make an angle equal to a given angle ABC.

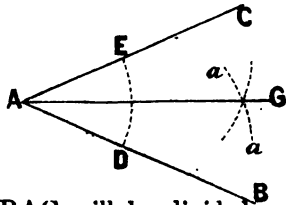
1. Draw the line CD: and from D as a centre, with the radius DE, draw an arc EF. 2. With the same radius, and from B, as a centre, describe the arc GH. 3. Set the distance GH off from E to F, and through F draw the line DI, which will be the angle required.



PROB. VII.

To bisect or divide a given angle BAC into two equal parts.

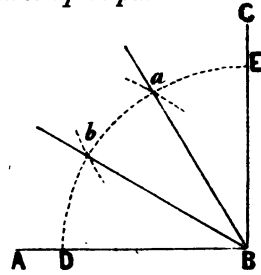
1. From the centre A, describe the arc DE. 2. From the centre D, with any radius longer than half of DE, describe the arc *a a*; and from the centre E, with the same radius, describe another arc cutting the former in G. 3. Draw the line AG, and the angle BAC will be divided into two equal parts or angles.



PROB. VIII.

To divide a right angle ABC into three equal parts.

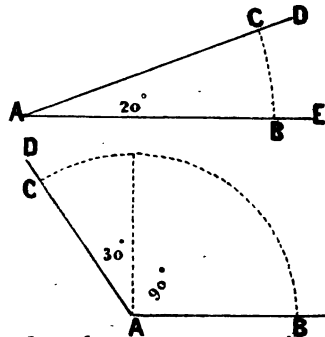
1. From B as a centre, describe an arc DE. 2. With the same radius, and E for a centre, cross the arc in *b*; and with the same radius, and D for a centre, cross the arc in *a*. 3. Draw the lines *a* B and *b* B, and the angle will be divided into three equal parts.



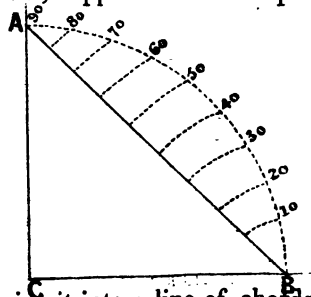
PROB. IX.

To make an angle of any proposed number of degrees.

1. Take the first 60 degrees from a scale of chords as a radius and from A as a centre, describe an arc BC. 2. Take the proposed number of degrees from the scale of chords, and set them off from B to C; then draw the line AD, and the angle will be made. If the angle is to contain more than 90 degrees, it must be taken at two operations.



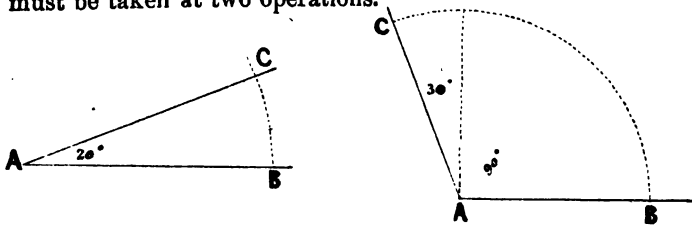
A scale of chords is made by transferring the divisions on the arc of a quadrant to its chord. Thus, suppose ACB is a quadrant and the right line BA the chord of its arc. Let this arc be divided into 90 equal parts or degrees: then if one foot of a pair of compasses be kept on the point B, and arcs successively described with the other from each of the 90 divisions on the arc to meet BA, those arcs will divide it into a line of chords.



PROB. X.

To find the number of degrees contained in an angle BAC .

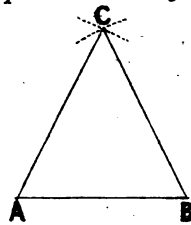
1. From A for a centre, and with a chord of 60 degrees for a radius, describe the arc BC . 2. Take the distance BC , and apply it to the scale of chords, which will show the number of degrees. If the angle contain more than 90 degrees, it must be taken at two operations.



PROB. XI.

Upon a given right line AB to make an equilateral triangle.

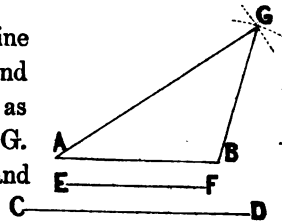
1. From the point A as a centre, and with the radius AB , describe an arc; and with the same radius AB , and from B as a centre, cross the first arc in C . 2. Draw the lines CA and CB , which will complete the triangle ABC .



PROB. XII.

To construct a triangle the sides of which are as the lines AB , CD , and EF .

1. From the centre A , with the line CD as a radius, describe an arc; and from the centre B , and the line EF as a radius, intersect the first arc in G . 2. Draw lines from A and B to G , and the triangle will be completed.

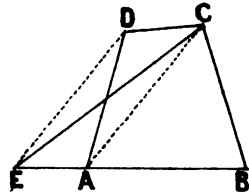


PROB. XIII.

To make a triangle BCE equal to a given quadrilateral figure $ABCD$.

Draw the diagonal AC , and parallel to it DE , meeting AB produced in E ; then draw CE , and ECB will be the triangle required.

For the triangles ADC , AEC being upon the same base AC , and under the same parallel ED , (by Cor. to Theo. 12.) will be equal, therefore if ABC be added to each, then $ABCD = BCE$.

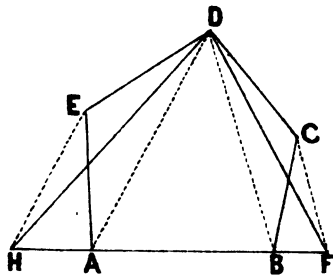


PROB. XIV.

To make a triangle DHF equal to a given five-sided figure $ABCDE$.

Draw DA and DB , and also EH and CF parallel to them, meeting AB produced in H and F ; then draw DH , DF , and the triangle DHF is the one required.

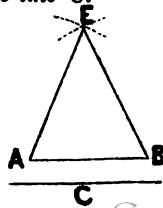
For the triangle $DEA = DHA$, and $DBC = DFB$ (by Cor. to Theo. 12.) therefore by adding these equations $DEA + DBC = DHA + DFB$, if to each of these ADB be added; then $DEA + ADB + DBC = ABCDE = (DHA + ABD + DFB) = DHF$.



PROB. XV.

To describe an isosceles triangle on the base AB , the other sides of which shall be equal to the line C .

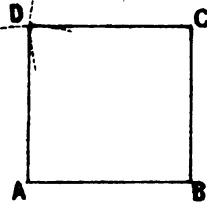
From the points A and B as centres, and the line C for a radius, describe arcs intersecting in E ; then draw the lines AE and BE , and the triangle will be completed.



PROB. XVI.

To construct a square upon a given line AB.

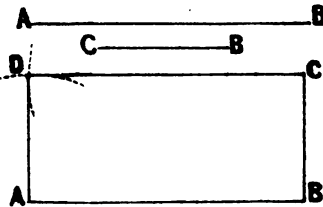
1. From the point B erect the perpendicular BC, equal to AB; and from A and C, with the radius AB, describe arcs intersecting in the point D.
2. Draw AD and CD, and the square will be completed. Or, erect two perpendiculars, from A and B, equal to AB, draw DC, and the square will be completed.



PROB. XVII.

To construct a rectangular parallelogram, the length and breadth of which shall be equal to two given lines AB and CB.

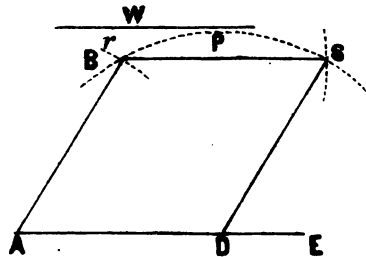
1. From the point B at the end of the base AB, erect BC perpendicular, and equal to the breadth CB. With the centre A, and radius BC, describe an arc; and with the centre C, and radius AB, describe another arc intersecting the former in D. 3. Draw the lines AD and CD, and the figure will be completed.



PROB. XVIII.

To make a rhombus equal to a given line W.

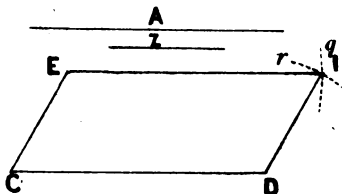
1. Draw the line AE to any length greater than the given line W, and from A set off the length of the line W to D. 2. From D as a centre, and AD as a radius, describe the arc P. 3. From A as a centre, and the same extent as a radius, describe the arc r , intersecting the former at B; and with the same extent as a radius, and B as a centre, intersect the first arc in S. 4. Draw the lines AB, BS, and SD, and the rhombus will be completed.



PROB. XIX.

To construct a rhomboid, the longest side of which shall be equal to the line *A*, and shortest side equal to the line *Z*.

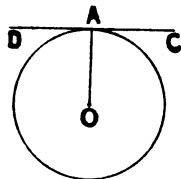
1. Draw the line *CD* equal to *A*; then take the length *Z* in the compasses, and (if there be no limitation to the angle), set it from the point *C* to the point *E*. 2. With the extent of the line *A* as a radius, and the point *E* as a centre, describe the arc *q*; then take the line *Z* again as a radius, and the point *D* as a centre and intersect the arc in *I*. 3. Draw the lines *CE*, *EI*, and *DI*, and the rhomboid *CEID* will be completed.



PROB. XX.

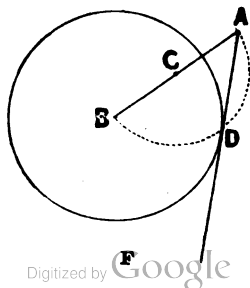
To draw a tangent to a given circle, that shall pass through a given point *A* in the circle.

1. Draw the radius *AO*: and at the end of it *A*, erect a perpendicular *AC*.
2. Produce the perpendicular to *D*, and *CD* will be the tangent required.



When the given point *A* is without the circle.

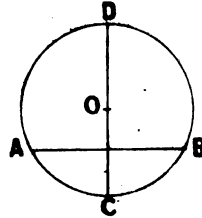
1. Draw the line *AB* from the given point to the centre of the circle *B*, and bisect *AB* in the point *C*. 2. With the radius *CB* or *CA*, and from *C* as a centre, describe the semicircle *ADB*, cutting the given circle in *D*; then draw *AD*, which will be the tangent required.



PROB. XXI.

To find the centre of a given circle.

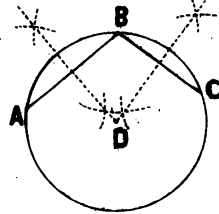
Draw the chord AB; bisect it at right angles with the line CD. Bisect CD, and it will give the centre O, as required.



PROB. XXII.

To describe the circumference of a circle, through three given points, A, B, and C.

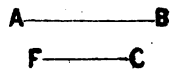
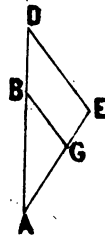
1. Draw any two right lines, AB and BC, joining in the assumed point B.
2. Bisect these two lines with two others drawn at right angles to them, and produce them till they meet in the point D.
3. With the radius DB, DC, or DA, and from D as a centre, describe a circle, which will pass through the points required.



PROB. XXIII.

To find a third proportional to two given right lines, AB and FC.

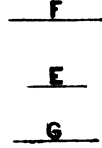
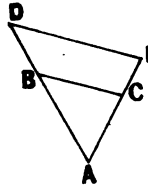
At either extremity of the given line AB, draw AE making any angle with it, take AG equal to the other given line FC, and join BG. Produce AB and make BD equal to FG, and through D, draw DE parallel to BG, and EG will be the third proportional to AB and FG, as required; that is, $AB : FC :: FC : GE$.



PROB. XXIV.

To find a fourth proportional to three given lines, F, E, and G.

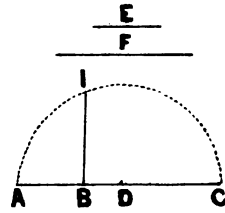
Draw two lines AD and AI, making any angle; make AB and BD equal to the given lines E, and AC equal to the line G; join BC, and through D, draw DI parallel to BC; and the line CI will be the fourth proportional to F, E, and G: therefore $F : E :: G : CI$



PROB. XXV.

To find a mean proportional between two given right lines, E and F.

Draw any right line, AC, and make AB equal to the line E, and BC equal to the line F; bisect AC in D; then from the centre D with the radius DA describe the semicircle AIC, and from B erect BI perpendicular to AC, meeting the circumference in I: BI will be the mean proportional between E and F.



CHAPTER IV.

LOGARITHMS.

DEFINITION AND PROPERTIES OF LOGARITHMS.

LOGARITHMS are artificial numbers, so related to each other and to the natural numbers, that the sum of any two Logarithms is the Logarithm of the product of their two natural numbers; and the difference of any two Logarithms is the Logarithm of the quotient of their two natural numbers.

If to a series of numbers in Geometrical Progression, whose common ratio is 10, and first term 1, we annex another series of numbers in Arithmetical Progression, whose first term is 0, and common difference 1. These latter numbers will be the Logarithms of the former, thus:

Numbers.	Logarithms.
1	0.00000
10	1.00000
100	2.00000
1000	3.00000
10000	4.00000 etc.

Since the Logarithm of 1 is 0 and the Logarithm of 10 is 1; the Logarithms of numbers between 1 and 10, will be greater

than 0, and less than 1, that is, they may be expressed by decimal fractions having a significant figure in the first decimal placè. As the Logarithm of 10 is 1, and the Logarithm of 100 is 2, the Logarithms of numbers between 10 and 100, will be greater than 1 and less than 2; or they will be mixed numbers, having 1 in the place of Integers, and the rest decimal fractions. In the same manner the Logarithms of all numbers between 100 and 1000, will have 2 in the place of Integers, and so on.

The integral part of a Logarithm is called its index, and this index is always a unit less than the number of figures in the Integer number, whose Logarithm it is. Thus: the index of the Logarithm of a number consisting of one figure, is 0, of two figures is 1, of three figures 2, &c.

The index of a Logarithm shows how many Integer figures the corresponding number consists of, being always one figure more than there are units in the index of the Logarithm.

The index of the Logarithm of a decimal fraction is negative, thus: the index of .684 is — 1, the index of .0684 is — 2, and of .00684 is — 3 and so on.

To find the Logarithm of any number less than 1000.

RULE. Seek in any Table of Logarithms for the given number, in the left hand column, opposite to which is the Logarithm sought with its proper index :

EXAMPLES.

The Logarithm of 78 is	1.8920946
„ „ 364 „	2.5611014
„ „ 987 „	2.9943172

To find the Logarithm of any number more than 1000.

RULE. Find the Logarithm of the first three figures, take the difference between this and the next Logarithm, which multiply by the remaining figures of the given number, add this

product to the Logarithm first found, and the sum prefixing the proper index, will be the Logarithm sought :

EXAMPLES.

Required the Logarithm of 1786.

The Logarithm of 178 is2504200

The difference between this and the Logarithm of 179 is 2433, which multiplied by 6, the remaining figure, gives 14598

Logarithm of 1786 = 3.2518798

The index becomes 3, being 1 less than the number of figures in the Integer.

Required the Logarithm of 84670.

The Logarithm of 846 is9273704

The difference between this and the Logarithm of 847 is 52, which multiplied by 70, the remaining figures, gives 3640

Logarithm of 84670 = 4.9277344

The index becomes 4, being 1 less than the number of figures in the Integer.

To find the Logarithm of a Fraction.

RULE. Reduce the Fraction to a decimal, and find the Logarithm of that decimal, prefixing the proper index.

EXAMPLES.

The Logarithm of $\frac{2}{3}$ or .80 is — 1.9030900

„ „ $\frac{3}{8}$ or .375 „ — 1.5740313

„ „ $\frac{1}{40}$ or .025 „ — 2.3979400

Or—Subtract the Logarithm of the denominator from the Logarithm of the numerator and the remainder will be the Logarithm of the fraction sought.

Required the Logarithm of $\frac{3}{16}$.

From Logarithm of 3	0.4771213
Subtract Logarithm of 16	1.2041200

Logarithm of $\frac{3}{16}$ or .1875 = 1.2730013

To find the natural number answering to any given Logarithm.

RULE. Seek in the tables for the given Logarithm, and if it be exactly found, the natural number corresponding to it will stand in the left hand column.

EXAMPLES.

The natural number corresponding to the Logarithm of

1.3617278 is	23
2.1205739 „	132
2.5301997 „	339

If the Logarithm is not found exactly in the tables, take the difference of the next greater and the next less Logarithms, and say: As this difference is to 1, so is the difference between the given Logarithm and the next lesser Logarithm, to a fourth number, which being added to the natural number of the less Logarithm, will give the natural number required.

EXAMPLE.

To find the natural number corresponding to the Logarithm of 2.8764321.

The Logarithm of the next less is	2.8762178	} difference is 5772
„ „ „ greater „	2.8767950	
Given Logarithm is	2.8764321	} difference is 2143
Next less Logarithm is	2.8762178	

Then as 5772 : 1 :: 2143 : .37 which added to 752, the natural number corresponding with the next less Logarithm, gives 752.37 the natural number required.

LOGARITHMIC ARITHMETIC.

MULTIPLICATION BY LOGARITHMS.

RULE. Add the Logarithm of the multiplier to the Logarithm of the multiplicand, and the sum will be the Logarithm of the product required.

EXAMPLES.

Multiply 384 by 462

The Logarithm of 384 is	2.5843312
„ „ 462 „	2.6646420
Product 177408 answering to,	<u>5.2489732</u>

Multiply 48.64 by 394.63

The Logarithm of 48.64 is	1.6869936
„ „ 394.63 is	2.5961901
Product 19194.80 answering to,.....	<u>4.2831837</u>

Multiply 46.75 by .3275

The Logarithm of 46.75 is	1.6697816
„ „ .3275 „	—1.5152113
Product 15.31 answering to,	<u>1.1849929</u>

In this last Example the + 1 that is to be carried from the decimals, cancels the — 1, and there remains + 1, in the upper line to be set down.

NOTE. Whatever is carried from the decimal part of the Logarithm is to be added to the affirmative indices, but subtracted from the negative. Likewise the indices must be added together when they are all of the same kind, that is, when they are all affirmative or negative; but when they are of different kinds, the difference must be found, which will be of the same denomination with the greater.

DIVISION BY LOGARITHMS.

RULE. From the Logarithm of the dividend, subtract the Logarithm of the divisor, and the remainder will be the Logarithm of the quotient.

EXAMPLES.

Divide 28643 by 4896.

The Logarithm of 28643 is.....	4.4570185
” ” 4896 „.....	3.6898414
	<hr/>
Quotient 5.8503 answering to,.....	0.7671771
	<hr/>

Divide 28.643 by 48.96.

The Logarithm of 28.643 is	1.4570185
” ” 48.96 „	1.6898414
	<hr/>
Quotient .58503 answering to	—1.7671771
	<hr/>

THE RULE OF THREE BY LOGARITHMS.

RULE. Add the Logarithms of the second and third terms together, and from the sum subtract the Logarithm of the first term, the remainder will be the Logarithm of the fourth term.

EXAMPLE.

If 89 maunds of Rice cost 254 Rupees, what will 568 maunds cost?

The Logarithm of 254 is.....	2.4048337
” ” 568 „	2.7543483
	<hr/>
	5.1591820
” ” 89 is.....	1.9493900
	<hr/>
Quotient 1621 Rs. nearly, answering to	3.2097920

INVOLUTION OR RAISING A POWER BY LOGARITHMS.

RULE. Multiply the Logarithm of the root, by the index of the power, and the product will be the Logarithm of the required power.

EXAMPLES.

Required the square of 25.

The Logarithm of 25 is	1.3979400
Multiplied by the index,	2
	2.7958800
Square 625, answering to	2.7958800

Required the 365th power of 1.0045.

The Logarithm of 1.0045 is	0.0019499
Multiplied by the index	365
	97495
	116994
	58497
	0.7117135
Power 5.148888, answering to	0.7117135

EVOLUTION OR EXTRACTING ROOTS BY LOGARITHMS.

RULE. Divide the Logarithm of the power by its index, and the quotient will be the Logarithm of the root required.

EXAMPLES.

Let it be required to extract the square root, the cube root, and the biquadrate root of 19.

The Logarithm of 19 is 1.2787536.

$$2 \overline{) 1.2787536}$$

0.6393768 = Logarithm ,, 4.359 for the square root.

$$3 \overline{) 1.2787536}$$

0.4262512 = ,, ,, 2.668 for the cube root.

$$4 \overline{) 1.2787536}$$

0.3196884 = ,, ,, 2.088 for the biquadrate root.

OF LOGARITHMIC SINES, TANGENTS, ETC.

If the radius be supposed any number of equal parts as 10 or 100, etc. the sine, tangent, etc. of every arc, must consist of some number of those equal parts, and by computing them in parts of the radius, we obtain tables of sines, tangents, etc. to every arc of the quadrant called natural sines, tangents, etc. and the Logarithms of these, give the Logarithmic sines, tangents, etc. which are usually found in all mathematical tables containing Logarithms.

These Tables of Logarithmic sines, tangents, etc. are carried out to 90 degrees or a Quadrant, (for the sine, tangent, etc. of any arc, has the same value as the sine, tangent, etc. of the supplement of that arc; so that, when an arc is greater than 90 degrees, subtract it from 180 degrees, and take the sine, tangent, etc. of the remainder, for that of the arc given) the degrees from 0 to 45 being generally printed at the top of each page in the table, and the minutes descending from the top to the bottom of the page, in the *left* hand column; and from 45 to 90° the degrees are found at the bottom of the page and the minutes ascending in the *right* hand column.

EXAMPLES.

The Logarithmic Sine of 35° 31' is	9.7641311
„ Co-Tangent „ 54° 23' „	9.8551372
„ Secant „ 40° 53' „	10.1214530

Should the arc consist of any parts of a minute, intermediate to those found in the table, take the difference between the tabular sine, tangent, etc. of the given degrees and minutes and of the minute next greater, then say: As 1 minute or 60 seconds: the given intermediate part :: the whole difference: the proportional part required.

EXAMPLE.

Required the Logarithmic Tangent of 21° 38' 24"	
The Tangent of 21° 38' is ... 9.5983540	} Difference is 3685.
„ „ „ 21° 39' „ ... 9.5987225	

Then as $60'' : 24'' :: 3685 : 1474$ which added to the Logarithmic tangent of $21^\circ 38'$, viz: 9.5983540 gives 9.5985014 as the Logarithmic tangent of $21^\circ 38' 24''$.

To find the arc corresponding to a given Logarithmic sine, tangent, etc.

Take the difference between the next less and greater tabular Logarithm, then say: As this difference : $1'$ or $60'' ::$ the difference between the given Logarithm and the next less : the proportional part required.

EXAMPLE.

Required the arc corresponding to the Logarithmic Sine 9.7453892.

The next less Logarithm,	}	Difference is 1887.
viz: $33^\circ 48'$ is ... 9.7453056		
The next greater Logarithm,	}	Difference is 836.
viz: $33^\circ 49'$ is .. 9.7454943		
The given Logarithm is ... 9.7453892	}	Difference is 836.
The next less ,, ,, ... 9.7453056		

Then as $1887 : 60'' :: 836 : 26''$ which added to $33^\circ 48'$ gives $33^\circ 48' 26''$ as the arc required.

CHAPTER V.

TRIGONOMETRY.

PLANE TRIGONOMETRY.

THE word *Trigonometry* signifies the measuring of triangles, but under this name is generally comprehended the art of determining the positions and dimensions of the several unknown parts of extension, by means of some parts which are already known. If we conceive the different points which may be represented in any space to be joined together by right lines, there are three things offered for our consideration.

- 1st. The *length* of these lines.
- 2d. The *angles* which they form with one another.
- 3d. The *angles* formed by the *planes* in which these lines are drawn, or are supposed to be traced.

On the comparison of these three objects depends the solution of all questions that can be proposed concerning the measure of extension and its parts, and the act of determining all these things from the knowledge of some of them, is reduced to the solution of this general question, viz: knowing three of the six parts, the sides and angles, which constitute a rectilinear triangle, to find the other three.

Plane Trigonometry is the art of measuring and computing the sides and angles of plane triangles.

There are three methods of resolving triangles viz: Geometrical Construction, Arithmetical Computation, and Instrumental Operation; of which the first two will here be treated.

In the First Method. The triangle is constructed, by making the parts of the given magnitudes, viz: the sides from a scale of equal parts, and the angles from a scale of chords, or by some other instrument. Then measuring the unknown parts by the same scales or instruments, the solution will be obtained near the truth.

In the Second Method. Having stated the terms of the proportion according to the proper rule or theorem, resolve it like any other proportion, in which a fourth term is to be found from three given terms, by multiplying the second and third together, and dividing the product by the first, in working with the natural numbers; or, in working with the Logarithms, add the Logarithms of the second and third terms together, and from the sum take the Logarithm of the first term; then the natural number answering to the remainder is the fourth term sought.

Every triangle has six parts; viz. three sides and three angles, and in every triangle proposed, there must be given three of these parts, to find the other three; also, of the three parts that are given, one of them at least must be a side; because, with the same angles, the sides may be greater or less in any proportion.

GENERAL PROPERTIES OF PLANE TRIANGLES.

1. If any three parts of a plane triangle be given (one part being a side) any required part may be found by construction and calculation.
2. If two angles of a plane triangle are known, the third angle is found by subtracting their sum from 180° .

3. In a right-angled plane triangle, if either acute angle be taken from 90° , the remainder will express the other acute angle.

4. The sum of the three angles is equal to two right angles.

5. The greater side is opposite the greater angle, and the less side to the less angle.

6. The sum of any two sides is greater than the third and the difference of any two sides is less than the third.

7. The triangle, is equilateral, isoscelar, or scalene according as it has its three angles all equal, or two of them equal, or all three unequal: and vice versâ.

8. The angles opposite the two least sides are acute.

9. The obtuse angle, if there is one, for there cannot be more, must be opposite the greatest side.

10. Of the two segments intercepted between the perpendicular to the base, and the two angles at the base, the greatest segment lies next to the greatest side, and the least segment next to the least side.

11. The greatest angle at the base lies next the least side, and least segment, and the least angle at the base lies next the greatest side and greatest segment.

There are four cases in Plane Trigonometry which are comprised in the following:

CASE 1st. Having the angles and one side, to find either of the other sides.

CASE 2nd. Having two sides, and an angle opposite to one of them, to find the other two angles and the third side.

CASE 3rd. Having two sides, and the angle between them, to find the other two angles and the third side.

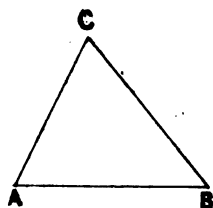
CASE 4th. Having the three sides, to find any angle.

Before we proceed to the solution of these four Cases, it is necessary to premise the following Theorems.

THEO. I.

In any plane triangle ABC, the sides are proportional to the sines of their opposite angles, that is, the Sine of C : AB :: the Sine of A : BC, and the Sine of C : AB :: the Sine of B : AC ; also, the Sine of B : AC :: the Sine of A : BC.

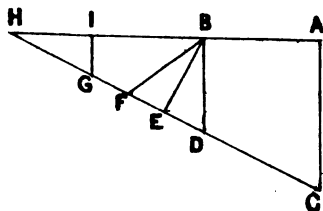
(By Theo. 10. Chap. II.) the half of each side is the sine of its opposite angle ; but the sines of those angles, in tabular parts, are proportional to the sines of the same in any other measure ; and therefore the sines of the angles will be as the halves of their opposite sides : And since the halves are as the wholes, it follows, that the sines of their angles are as their opposite sides, that is the Sine of C : AB :: the Sine of A : BC, etc. Q. E. D.



THEO. II.

In any plane triangle ABC, the sum of the two given sides AB and BC, including a given angle ABC, is to their difference, as the tangent of half the sum of the two unknown angles A and C is to the tangent of half their difference.

Produce AB, make HB = BC, and join HC : Let fall the perpendicular BE, and that will bisect the angle HBC (by Theo. 9. Chap. II.), through B draw BD parallel to AC, make HF = DC, and join BF ; take BI = BA, and draw IG parallel to BD, or AC.



It is then plain, that AH will be the sum, and HI the difference of the sides AB and BC ; and since HB = BC, and BE is perpendicular to HC, therefore HE = EC (by Theo. 8. Chap. II.) ; and since BA = BI, and BD and IG are parallel to AC, therefore GD = DC = FH, and consequently HG = FD, and $\frac{1}{2}$ HG = $\frac{1}{2}$ FD or ED.

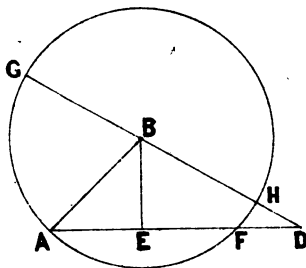
Again, EBC , being half of HBC , will be also half the sum of the angles A and C , (by Theo. 4. Chap. II). Also since HB HF , and the included angle H , are severally equal to BC , CD , and the included angle BCD ; therefore (by Theo. 6, Chap. II.) $HBF = DBC = BCA$ (by Part 2. Theo. 3. Chap. II.) and since $HBD = A$ (by Part. 3. Theo. 3. Chap. II.) and $HBF = BCA$; therefore FBD is the difference, and EBD , half the difference of the angles A and C : then, making BE the radius, it is plain that EC will be the tangent of half the sum, and ED the tangent of half the difference of the two unknown angles A and C : now, IG being parallel to AC ; $AH : IH :: CH : GH$. (by Cor. I. Theo. 19, Chap. II.) But the wholes are as their halves, or $AH : IH :: CE : ED$, that is, as the sum of the two sides AB and BC , is to their difference; so is the tangent of half the sum of the two unknown angles A and C , to the tangent of half their difference. Q. E. D.

THEO. III.

In any plane triangle ABD ; the base AD , will be to the sum of the other sides, AB , BD , as the difference of those sides, is to the difference of the segments of the base, made by the perpendicular BE ; viz: the difference between AE and ED .

Produce BD , till $BG = AB$

the lesser side; and on B as a centre with the distance BG or BA describe a circle, $AGHF$ which will cut BD and AD in the points H and F : Then it is plain, that GD will be the sum, and HD the difference of

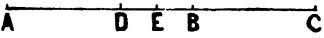


the sides AB and BD ; also since $AE = EF$, (by Theo. 8, Chap. II.) therefore FD is the difference of AE and ED , the segments of the base: But (by Theo. 16. Chap II.) $AD : GD :: HD : FD$; that is, the base is to the sum of the other sides, as the difference of those sides, is to the difference of the segments of the base. Q. E. D.

THEO. IV.

If to half the sum of two quantities be added half their difference; the sum will be the greatest of them: and if from half the sum be subtracted half their difference, the remainder will be the least of them.

Let the two quantities be represented by AB and BC;

(making one continued line;)  whereof AB is the greatest, and

BC the least; bisect the whole line AC in E, and make $AD = BC$; then it is plain, that AC is the sum, and BD the difference of the two quantities; and AE or EC their half sum, and DE or EB their half difference. Now if to AE we add EB, we shall have AB the greatest quantity; and if from EC we take EB, we shall have BC the least quantity. Q. E. D.

Cor. If from the greatest of two quantities we take half the difference of them, the remainder will be half their sum; or if to half their difference be added the least quantity, their sum will be half the sum of the two quantities.

SOLUTIONS OF THE CASES IN PLANE TRIGONOMETRY.

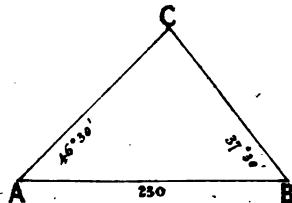
CASE 1st. *Having the angles and one side, to find either of the other sides.*

RULE. As the sine of the angle opposite the given side, is to the given side, so is, the sine of the angle opposite the required side, to the required side.

In the triangle ABC, there is given the angle A $46^{\circ} 30'$, AB 230, and the angle B $37^{\circ} 30'$ to find AC and BC.

GEOMETRICALLY.

Draw a blank line, upon which set off AB 230 from a scale of equal parts, at the point A of the line AB, make an angle of $46^{\circ} 30'$ by a blank line; and at the point B of the line AB, make an angle of $37^{\circ} 30'$ by another blank line; the



intersection of these lines gives the point C, making the triangle ABC. Measure AC and BC from the same scale of equal parts that AB was taken, and we have the answer required.

BY CALCULATION.

By (Cor. 1. Theo 5. Chap. II.) 180° —the sum of the angles A and B = C.

Or $180^\circ - (46^\circ 30' + 37^\circ 30') = 96^\circ 00' = C$

Then :

As the Sine of C	or	$96^\circ 00'$	.....	9.9976143
: AB	„	230	.....	2.3617278
:: the Sine of A	„	$46^\circ 30'$	.....	9.8605622
				<u>12.2222900</u>
: BC	„	167.76	answering to	<u>2.2246757</u>

AGAIN.

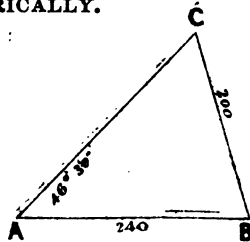
As the Sine of C	„	$96^\circ 00'$	.....	9.9976143
: AB	„	230	.....	2.3617278
:: the Sine of B	„	$37^\circ 30'$	.....	9.7844471
				<u>12.1461749</u>
: AB	„	140.78	answering to	<u>2.1485606</u>

CASE 2nd. *Having two sides, and an angle opposite to one of them, to find the other two angles and the third side.*

RULE. As the side opposite the given angle, is to the Sine of that angle, so is the side opposite the required angle to the Sine of that angle.

In the triangle ABC, there is given AB 240, the angle A $46^\circ 30'$ and BC 200; to find the angle C being acute, the angle B and the side AC. GEOMETRICALLY.

Draw a blank line, on which set off AB 240 from a scale of equal parts; at the point A of the line AB, make an angle of $46^\circ 30'$ by a blank line; with BC 200 from the same scale of equal parts that AB was taken, and one leg of the compasses in



B describe the Arc DC to cut the last blank line in the points D and C. Now if the angle C had been required obtuse, lines from D to B and to A, would constitute the triangle; but as it is required acute, draw the lines from C to B and to A, and the triangle ABC is constructed. From a line of chords let the angles B and C be measured, and AC from the same scale of equal parts that AB and BC were taken; and we have the answer required.

BY CALCULATION.

As BC	or	200	.....	2.3010300
<hr/>				
: the Sine of A	,,	46° 30'	.....	9.8605622
:: AB	,,	240	.....	2.3802112
<hr/>				
12.2407734				
<hr/>				
: the Sine of C	,,	60° 31'	.....	9.9397434
Then 180—the sum of the angles A and C, gives the angle B				
Or $180^{\circ} - (46^{\circ} 30' + 60^{\circ} 31') = 72^{\circ} 59' = B.$				

AGAIN.

As the Sine of A	or	46° 30'	.....	9.8605622
<hr/>				
: BC	,,	200	.....	2.3010300
:: the Sine of B	,,	72° 59'	.....	9.9805577
<hr/>				
12.2815877				
<hr/>				
: AC	,,	263.65	.....	2.4210255
<hr/>				

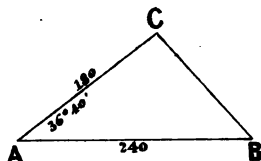
CASE 3rd. *Having two sides, and the angle between them, to find the other two angles and the third side.*

RULE. As the sum of the two given sides, is to their difference, so is, the Tangent of half the sum of the unknown angles, to the Tangent of half their difference. Half the difference thus found added to half their sum, gives the greater of the two angles, and deducted, leaves the lesser. The third side is found by Case 1st.

In the triangle ABC , there is given AB 240, the angle A $36^\circ 40'$, and AC 180; to find the angles C and B , and the side BC .

GEOMETRICALLY.

Draw a blank line, on which from a scale of equal parts, lay off AB 240: at the point A of the line AB , make an angle of $36^\circ 40'$ by a blank line, on which from A , lay off AC 180 from the same scale of equal parts; measure the angles C and B , and the side BC , as before; and we have the answer required.



BY CALCULATION.

The sum of the two given sides or $240 + 180 = 420$

The difference " " " $240 - 180 = 60$

$180^\circ - 36^\circ 40'$ or angle $A = 143^\circ 20'$ or sum of unknown angles B and C , the half sum of which is $71^\circ 40'$

Then:

As $AB + AC$ or 420 2.6232493

: $AB - AC$,, 60 1.7781513

:: Tangent of $71^\circ 40'$ 10.4796948

12.2578461

: Tangent of $23^\circ 20'$ answering to 9.6345968

Then $71^\circ 40' + 23^\circ 20' = 95^\circ 00' = C$

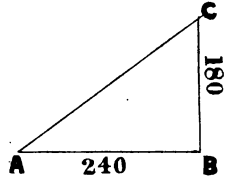
And $71^\circ 40' - 23^\circ 20' = 48^\circ 20' = B$

The third side BC is found by Case 1st thus:

As Sine of B : AC :: Sine of A : BC .

If the angle included be a right angle, add the Radius to the Logarithm of the less side, and from the sum subtract the Logarithm of the greater side; the remainder or sum, will be the Tangent of the angle opposite to the less side.

In the right-angled triangle ABC there is given AB 240, BC 180, and the angle B 90° to find the angles A and C and the side AC.



Then,

To the Logarithm of less side or 180	2.2552725
Add Radius	10.0000000
	12.2552725

And deduct the Logarithm of greater side or 240... 2.3802112

Tangent of A = 36° 52' answering to ... 9.8750613

Then $180^\circ - (90^\circ 00' + 36^\circ 52') = 53^\circ 08' = C$

And, As Sine of C : AB :: Sine of B : AC.

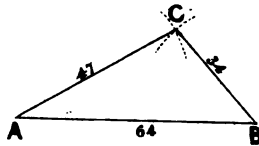
CASE 4th: *Having the three sides, to find any angle.*

RULE. As the longest side or base, is to the sum of the other two sides, so is the difference of those sides, to the difference of the segments of the base, formed by a perpendicular let fall from its opposite angle. Half the difference of the segments thus found, added to half the base gives the greater segment, and subtracted leaves the lesser—whence we have two right-angled triangles with two sides given, to find the other two angles and the third side, by Cases 1st and 2nd.

In the triangle ABC, there is given AB 64, AC 47, BC 34 : to find the angles A, B, and C.

GEOMETRICALLY.

Draw a blank line, on which from a scale of equal parts lay off AB 64, from A with the line AC 47, describe an arc, and from B with the line BC 34 describe another arc, to the intersection point at C, draw AC and BC and ABC is the triangle required.



BY CALCULATION.

From the point C; let fall the perpendicular CD, on the base AB; it will divide the triangle into two right-angled ones ADC and CBD, as well as the base AB into the two segments AD and DB,

The longest side or base $AB = 64$.

The sum of the other two sides or $AC + BC = 47 + 34 = 81$

The difference „ „ „ $AC - BC = 47 - 34 = 13$

Then:

$As^2 AB$	or 64	1.8061800
: $AC + BC$ „	81	1.9084850
:: $AC - BC$ „	13	1.1139434
		3.0224284

: $AD - DB$ „ 16.46 answering to 1.2162484

The half difference or 8.23 added to the half base or 32 = 40.23 or greater segment, and deducted = 23.77 or lesser segment.

Having now two right-angled triangles ADC and CBD with two sides given in each, the remaining angles and side are easily found by Cases 1st and 2nd.

HEIGHTS AND DISTANCES.

Having given the solutions of the four cases in Plane Trigonometry, we will proceed to apply the same, by a few examples, in determining the heights and distances of inaccessible objects.

EXAMPLE 1.

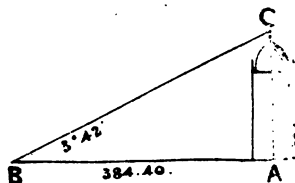
What is the height of a Musjid, the distance of which was 384.40 yards from where I stood, and the angle of elevation to the top $3^\circ 42'$?

We have here given the angle

$A = 90^\circ$

The angle $B = 3^\circ 42'$, and the side $BA = 384.40$ yards.

The angle $C = (90^\circ - B) = 86^\circ 18'$.



BY CASE 1ST.

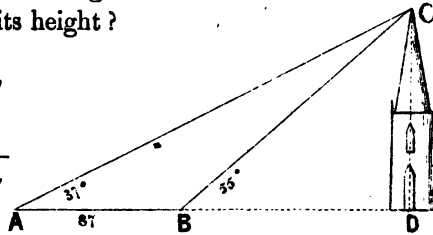
As Sine of C or $86^{\circ} 18'$	9.999093
: BA or 384.40	<u>2.584783</u>
:: Sine of B	<u>8.809777</u>
	<u>11.394560</u>
: AC or 24.90 yards, the height required	<u>1.395467</u>

EXAMPLE 2.

Being desirous of knowing the height of a Steeple CD, which could not be approached nearer than B; the angle of altitude DBC was found to be 55° ; having measured a line from B to A of 87 feet, the angle of altitude CAB was found to be 37° ; Required its height ?

From DBC = $55^{\circ} 00'$
 Take CAB = $37^{\circ} 00'$

 Angle ACB = $18^{\circ} 00'$



BY CASE 1ST.

As Sine angle ACB or $18^{\circ} 00'$	9.4899824
: AB or 87	<u>1.9395198</u>
:: Sine angle CAB ,, $37^{\circ} 00'$	<u>9.7794630</u>
	<u>11.7189828</u>
: BC or 169. 43	answering to
	<u>2.2290004</u>

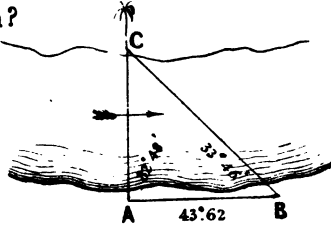
AGAIN.

As Radius 90° or Sine of angle BDC	10.0000000
: BC or 169.43	<u>2.2290004</u>
:: Sine angle CBD or $55^{\circ} 00'$	<u>9.9133645</u>
	<u>12.1423649</u>
: DC or 138.80 feet, the height required	<u>2.1423649</u>

EXAMPLE 3.

The breadth of the River Ganges at Benares being required, a base line AB was measured on one side of 43 Chs. 62 Lks. and the angles subtended by a tree on the opposite edge at each end of the base were, at A $82^{\circ} 48'$ and at B $33^{\circ} 46'$. What is the breadth?

We have here given the angle $A = 82^{\circ} 48'$, the angle $B = 33^{\circ} 46'$, consequently the angle $C = 180^{\circ} - (82^{\circ} 48' + 33^{\circ} 46') = 63^{\circ} 26'$ and the side $AB = 43.62$.

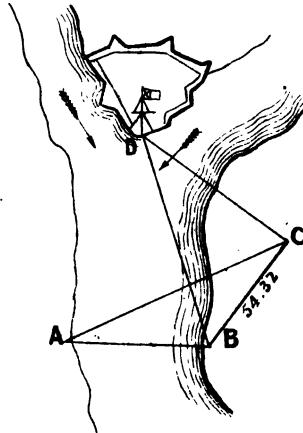


BY CASE 1ST.

As sine of C or $63^{\circ} 26'$	9.951538
: AB or 43.62	1.639685
:: Sine of B or $33^{\circ} 46'$	9.744928
	<hr/>
	11.384613
	<hr/>
: AC or 27 Chs. 11 Lks. the breadth required ...	1.433075

EXAMPLE 4.

Required the distance of the Fort Flagstaff at Allahabad, from two given points A and B on each side of the Ganges. To obtain which I measured a base $BC = 54.32$ Chs. the angles subtended with the point A at each end of the base were $ABC 120^{\circ} 44'$ and $BCA 24^{\circ} 16'$, also the angles subtended with the Fort Flagstaff at each end of the base were $CBD 15^{\circ} 42'$ and $BCD 117^{\circ} 31'$. What are the respective distances?



In the Triangle BCD, the angle CDB = $180^\circ - (\text{BCD} + \text{CBD}) = 46^\circ 47'$.
 „ „ CBA, the angle CAB = $180^\circ - (\text{ABC} + \text{BCA}) = 35^\circ 00'$.
 „ „ ABD the angle DBA = $\text{ABC} - \text{DBC} = 105^\circ 02'$.

Then,

BY CASE 1ST.

As Sine of CDB or $46^\circ 47'$	9.862590
: BC or 54.32	1.734959
:: Sine of BCD or $117^\circ 31'$	9.947863
	<hr/>
	11.682822
: BD or 66.11 Chs. the distance required	1.820232
Again,	<hr/>

BY CASE 1ST.

As Sine of CAB or $35^\circ 00'$	9.758591
: BC or 54.32	1.734959
:: Sine of BCA or $24^\circ 16'$	9.613825
	<hr/>
	11.348784
: BA or 38.92 Chs. the distance required	1.590193
	<hr/>

BY CASE 3RD.

$\text{BD} + \text{AB} = 105.03$ and $\text{BD} - \text{AB} = 27.19$.

Also $180^\circ - \text{ADB}$ or $105^\circ 02' = 74^\circ 58'$ or sum of unknown angles, the half sum of which is $37^\circ 29'$.

Then,

As $\text{BD} + \text{AB}$ or 105.03	2.021313
: $\text{BD} - \text{AB}$ „ 27.19	1.434409
:: Tangent of $37^\circ 39'$	9.884718
	<hr/>
	11.319127
: Tangent of $11^\circ 13'$	9.297814
	<hr/>

$37^\circ 29' + 11^\circ 13' = 48^\circ 42'$ or angle DAB

$37^\circ 29' - 11^\circ 13' = 26^\circ 16'$ or „ ADB

Lastly,

BY CASE 1ST.

As Sine of BDA or $26^{\circ} 16'$	9.645961
: AB or 38.92	1.590193
:: Sine of ABD or $105^{\circ} 02'$	9.984876
	<hr/>
	11.575069
	<hr/>
: AD or 84.94 Chs. the distance required	1.929108
	<hr/>

EXAMPLE 5.

The angle subtended from a point C between two objects at A and B, exactly 23 Chs. 42 Lks. apart, being $31^{\circ} 47'$, what are the angles at A and B, the distance from C to B being 35 Chs. 64 Lks.?

BY CASE 2ND.

As AB or 23.42	1.369586
: the Sine of C or $31^{\circ} 47'$	9.721570
:: CB or 35.64	1.551937
	<hr/>
	11.273507
	<hr/>
: the Sine of A or $53^{\circ} 17'$	9.903921
	<hr/>
Then $180^{\circ} - (31^{\circ} 47' + 53^{\circ} 17') = 94^{\circ} 56'$ or angle B.	

EXAMPLE 6.

Required the angle contained between the two cocoanut trees on the Taj at Agra, the distance between them being supposed 53 feet, and the distance of each tree from where I stood at C was A 1388 feet and B 1353 feet?

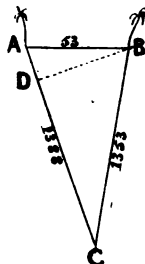
In this Example we have,

AC = 1388 feet

BC = 1353 „

AB = 53 „

Let fall the perpendicular BD on the base or longest side AC—



BY CASE 3RD.

Then,

As AC or 1388 feet 3.142389

: AB + BC „ 1406 „ 3.147985

∴ AB - BC „ 1300 „ 3.113943

6.261928

: DC - AD „ 1317 „ 3.119539

Then $\frac{1388}{2} + \frac{1317}{2} = CD$ or 1352.50 feetAnd $\frac{1388}{2} - \frac{1317}{2} = AD$ „ 35.50 „

Again

BY CASE 2ND.

As BC or 1353 feet 3.131297

: Radius or Sine of BDC = 90° 10.000000

∴ DC or 1352.50 feet 3.131137

13.131137

: DBC or 88° 27' 9.999840

$180^\circ - (90^\circ + 88^\circ 27') = 1^\circ 33'$ or DCB the angle between the two cocoanut trees.

If it is required to find the angles A and B of the triangle ABC, the angle ABD can be found in the same manner as DBC when $ABD + DBC = ABC$, and $180^\circ - (ABC + ACB) = BAC$.

CHAPTER VI.

MENSURATION OF PLANES.

DEFINITIONS.

AREA, means the superficial content of any plane Geometrical figure, estimated by the squares of some known lineal measure as inches, links, chains, etc., which in surveying are converted into square perches, roods, and acres.

The English statute acre contains 4840 square yards, subdivided into roods and perches of which 40 perches make one rood and 4 roods make one acre: The perch is $16\frac{1}{2}$ feet, giving $272\frac{1}{4}$ square feet, or $30\frac{1}{4}$ square yards, which multiplied by 40, gives 1210 square yards in one rood, and again multiplied by 4 gives 4840 square yards in the acre.

The best method of taking the length and breadth of figures for ascertaining areas, is in chains and links, and Gunter's Chain in general use with Surveyors is the best adapted for this purpose. It is divided into 100 links, each link being 7.92 inches, giving exactly 22 yards or 66 feet in length, and equal to 4 perches, so that one square chain is equal to 16 square perches or the tenth part of an acre, consequently 10 square chains, are equal to one acre, and as the chain is divided into 100 links, every superficial chain contains 10,000 square links and every superficial acre 100,000 square links.

If therefore the content of a field is made up in square links, dividing the number by 100,000, or which is the same thing, if from the content we cut off the last five figures, the remaining figure towards the left hand, gives the content in acres and consequently the number of acres at first sight, the remainder being decimal parts of an acre, which latter being multiplied by 4 and 40, gives the roods and perches.

The area of any plane figure, is the measure of the space contained within its extremes or bounds.

This area, or the content of the plane figure, is estimated by the number of little squares that may be contained in it; the side of those little measuring squares being an inch, or a foot, or a yard, or any other fixed quantity. And hence the area or content is said to be so many square inches, or square feet, or square yards, &c.

Thus, if the figure to be measured be the rectangle ABCD, and the little square E, whose side is one inch, be the measuring unit proposed: then as often as the said little square is contained in the rectangle, so many square inches the rectangle is said to contain—which in the present case is 16.

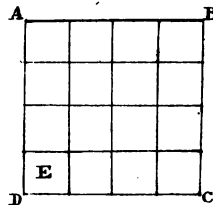


Table of Square Measure.

144	Square Inches	make	1	Square Foot	.....	<i>Ft.</i>
9	Square Feet	.....	1	Square Yard	.....	<i>Yd.</i>
30½	Square Yards	.....	1	Square Perch	...	<i>Per.</i>
40	Square Perches	...	1	Rood	.....	<i>Rd.</i>
4	Roods	.....	1	Acre	.....	<i>Acr.</i>
<i>Sq. In.</i>			<i>Sq. Ft.</i>			
144	=	1	=	<i>Sq. Yd.</i>		
1296	=	9	=	1	<i>Sq. Pole.</i>	
39204	=	272½	=	30½	=	1 <i>Rd.</i>
1568160	=	10890	=	1210	=	40 = 1 <i>Acre.</i>
6272640	=	43560	=	4840	=	160 = 4 = 1

To determine the area of a Rectangular Parallelogram.

RULE.—Multiply the length by the breadth and the product will be the area.

EXAMPLES.

Suppose the side of a square to be 10 Chs. 48 Lks. what is the area? Answer, 10 Acr. 3 Rd. 37 Per.

$10.48 \times 10.48 = 10.98304$, dividing by 100000,
or cutting off 5 figures from the right hand gives, Acr. 10.98304

	4
Rds.	3.93216
	40
Per.	37.28640

The length of an oblong being 34 Chs. 56 Lks. and the breadth 22 Chs. 64 Lks. what is the area?

$34.56 \times 22.64 = 78.24384$ or 78 Acr. 0 Rd. 38 Per.

—

To determine the area of a triangle.

RULE.—Multiply the base or length by half the perpendicular, let fall thereon from the opposite angle, and the product will be the area.

EXAMPLES.

What is the area of a triangle whose base is 23.22 Chs. and altitude or perpendicular height 10.44 Chs.?

$\frac{23.22 + 10.44}{2} = 12.12$ Acr. or 12 Acr. 0 Rd. 19 Per.

Required the area of a right-angled triangle whose base is 3.54 Chs. and perpendicular 2.44 Chs.?

$\frac{3.54 + 2.44}{2} = 0.43$ Acr. or 0 Acr. 1 Rd. 29 Per.

The same result would be obtained if the perpendicular were to be multiplied by half the base, or if the base and perpendicular were to be multiplied together, and half the product taken for the area.

*To find the area of a Trapezoid.**

RULE.—Add the breadth at each end together, and multiply the base by half their sum and the product will be the area.

EXAMPLE.

The base of a field is 5.54 Chs. the breadth at one end is 2.32 Chs. and at the other end 1.83 Chs. required the area ?

$$\frac{2.32 + 1.83}{2} \times 5.54 = 1.15 \text{ Acr. or } 1 \text{ Acr. } 0 \text{ Rd. } 24 \text{ Per.}$$

To find the area of a Trapezium.

RULE.—Take the diagonal length from one extreme corner to the other as a base, and multiply it by half the sum of the perpendiculars falling thereon from the other two corners, the product will be the area.

EXAMPLE.

A field whose diagonal length was 10.43 Chs. and lengths of perpendiculars 3.44 Chs. and 4.53 Chs. required the area ?

$$\frac{3.44 + 4.53}{2} \times 10.43 = 4.15 \text{ Acr. or } 4 \text{ Acr. } 0 \text{ Rd. } 24 \text{ Per.}$$

To find the area of a Rhombus or Rhomboid.

RULE. Multiply the base by the perpendicular height, and the product will be the area.

EXAMPLE.

Required the area of a Rhomboid, whose base is 2.13 Chs. and perpendicular height 2.04 Chs. ?

$$2.13 \times 2.04 = 0.43452 \text{ or } 0 \text{ Acr. } 1 \text{ Rd. } 29 \text{ Per.}$$

The area of all other figures whether regular or irregular, of how many sides soever they may consist, is determined by dividing the figure into triangles or trapezia, and measuring them separately, the sum of which will be the area of the figure thus :

* A four-sided figure having two opposite sides parallel, is called a *Trapezoid*.

To find the Area of an Irregular Polygon.

Draw diagonals dividing the proposed polygon into trapezia and triangles, then find the area of all these separately, and add them together for the content of the whole polygon.

EXAMPLE.

What is the content of the irregular figure ABCDEFGA, in which are given the following diagonals and perpendiculars:

AC 55 Chs. viz:

FD 52 „

GC 44 „

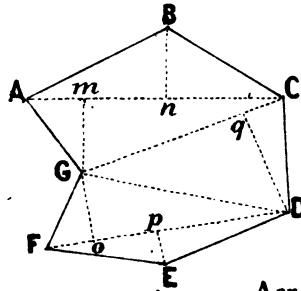
Gm 13 „

Bn 18 „

Go 12 „

Ep 8 „

Dq 23 „



Then,

AC	×	Bn	or	55	×	18	=	99.00
AC	×	Gm	or	55	×	13	=	71.00
GC	×	Dq	or	44	×	23	=	101.20
FD	×	Go	or	52	×	12	=	62.40
FD	×	Ep	or	52	×	8	=	41.00

374.60

4

2.40

40

Ac. Rds. Per.

Answer 374 „ 2 „ 16

16.00

The area of any figure may also be determined by a computation made from the bearings and distances of the boundary lines, which method will form a separate part of this work.

CHAPTER VII.

USEFUL PROBLEMS IN SURVEYING.

PROBLEM I.

To draw upon the ground a straight line through two given points.

Plant a picket, or staff, at each of the given points, then fix another between them, in such a manner that when the eye is placed at the edge of one staff, the edges of the other two may coincide with it. The line may then be prolonged by fixing up other staves. The accuracy of this operation depends greatly on fixing the staves upright, and, not letting the eye be too near the staff from whence the observation is made.

PROB. II.

To walk in a straight line from a proposed point to a given object.

Fix upon some point, as a bush, or a stone, or any mark that you find to be in a line with your given object, and walk forward, keeping the two objects strictly in line; selecting a fresh mark when you come within 20 or 30 paces of the one upon which you have been moving. Observe—that to walk in a direct line, it is always necessary to have two objects constantly in view.

PROB. III.

To trace a line in the direction of two distant points.

Let two persons separate to about 50 or 60 paces ; then, by alternately motioning each other to move right or left, they soon get exactly into line with the distant objects : or, for greater accuracy, they may hold up staves.

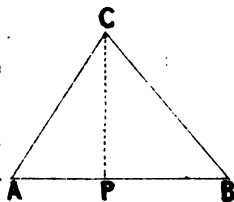
In sketching ground, it is constantly necessary to get in line between two objects : if these are not very distant, a well-drilled soldier can always do so within a few paces (near enough for sketching purposes) by fronting one object exactly, and then facing to the right about ; when, if he finds himself accurately fronting the other object, he will be tolerably well in line with them.

A right angle may also be formed very nearly by fronting an object, and then facing to the *right* or *left*.

PROB. IV.

To survey a triangular field ABC, by the chain.

Having set up marks at the corners, which is to be done in all cases where there are not sufficient marks existing, measure with the chain from A to P, where a perpendicular would fall from the angle C, and set up a mark at P, noting down the distance AP. Then complete the distance AB, by measuring from P to B. Having set down this measure, return to P, and measure the perpendicular PC. And thus, having the base and perpendicular, the area is easily found by multiplying the length AB by PC, and taking half the product. Or, the figure may be constructed by measuring an angle as CAB, and the two sides AC and AB. Or, measure one side AB, and the angles at A and B. By either



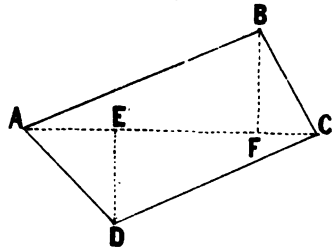
of these ways, the figure is easily planned; then by measuring the perpendicular CP on the plan, and multiplying it by half AB , the content is found.

PROB. V.

To measure a four-sided field $ABCD$.

Divide it into two triangles by a diagonal AC , and find the content of each, as in the last problem.

To take the plan of such a field, measure the four sides, and one of the angles, as ABC ; when the figure is easily constructed. Or, measure the diagonal AC , and the four angles BAC , CAD , BCA , and ACD .

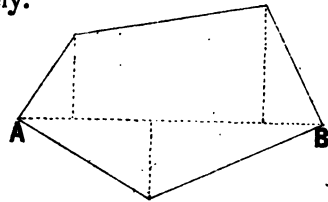


PROB. VI.

To measure any field by the chain only.

Divide it into triangles and trapeziums, by running lines across from corner to corner: then calculate the content of each triangle and trapezium separately.

To make the plan of any field, measure a base line AB across it, and having placed marks—such as a stick, with a bit of white paper on it—at each corner, as also similar marks to show the base line; put a mark at every point on the line, at which a perpendicular from a corner of the field will fall; which point may be judged with sufficient accuracy by the eye alone, when the chain is extended along the base line;

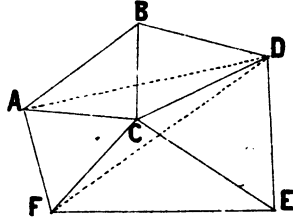


then measure these perpendiculars as off-sets. A diagram of the field, drawn by the eye, is better to note the measurements upon than a field-book.

PROB. VII.

To take the plan of any field with an instrument.

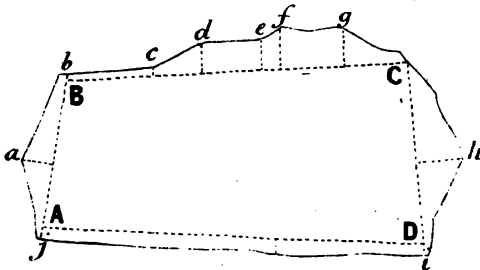
Plant the instrument at any point C, near the middle of the field, and having placed marks at every angle of it: measure the distances from the instrument to each corner; as also the angles ACB, BCD, DCE, &c.: when a plan can be easily formed of it. Or, the instrument may be placed at one of the corners, from whence the others are visible, as D; then measure the angles BDA, ADF, and FDE (formed by the dotted lines); then measure DE, DF, DA, and DB. Note the measures of the angles and lines on a rough figure drawn to resemble the true one.



PROB. VIII.

To measure a field with irregular boundaries.

Fix upon three or more stations, as A, B, C, D, and measure the angles ABC, BCD, ADC, and BAD; then measure the sides BC, CD, AD, and AB: and while doing this, take off-sets to *a, b, c, d, e, &c.*



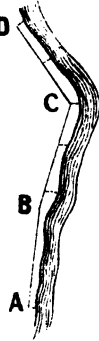
The imaginary figure A, B, C, D, may be formed outside the field or piece of ground, if more convenient.

PROB. IX.

To obtain the plan of a river.

Place marks at its principal bends A, B, C, D, D and with a theodolite or surveying compass take the bearings of the station lines AB, BC, CD, &c.; and when measuring these lines, take off-sets to all the smaller bends, as shewn in the diagram.

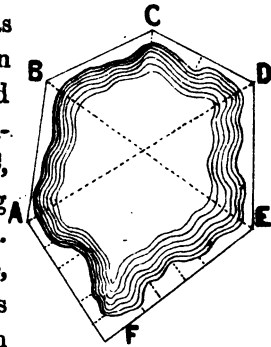
The plan may either be protracted in the field, or the bearings and measurements entered in a field-book.



PROB. X.

To take the plan of a wood, a lake, or marsh, &c.

Place marks A, B, C, &c. so as to form the most convenient station lines AB, BC, &c., all round the wood or marsh; then with a surveying compass take the bearings of AB, BC, CD, &c., going all round, measuring and taking off-sets as you proceed. If the survey be of a marsh or lake, *check* bearings should be taken across it, as from A and E to D, &c., which will insure greater accuracy, and cause the work to close (as it is termed) with proper exactness.

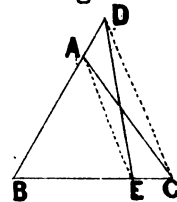
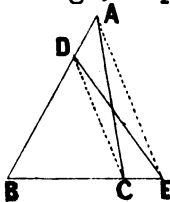


PROB. XI.

To change a triangle into another of equal extent, but different height.

Let ABC be the given triangle, D a point at the given height.

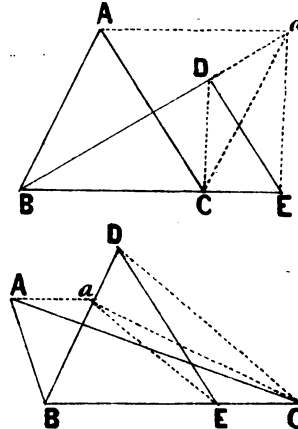
CASE I. Where the point D, is either in one of the sides, or in the prolongation of a side,
1. Draw a line from D to the opposite angle C.



2. Draw a line AE parallel thereto from A , the summit of the given triangle. 3. Join DE , and BDE is the required triangle.

CASE 2. When the point D , is neither in one of the sides, nor in the prolongation thereof. 1.

Draw an indefinite line $BDAa$, from B through the point D . 2. Draw from A , the summit of the given triangle, a line Aa , parallel to the base BC , and cutting the line BD in a . 3. Join aC , and the triangle BaC is equal to the triangle BAC ; and the point D being in the same line with Ba . 4. By the preceding case, find a triangle from D , equal to BaC ; join DC , draw aE parallel thereto, then join DE and BDE is the required triangle.

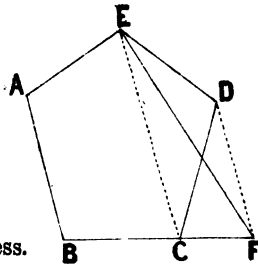


Corollary. If it be required to change the triangle BAC into an equal triangle, of which the height and angle BDE are given: 1. Draw the indefinite line BDA , making the required, angle with BC . 2. Take on BDA a point D at the given height: and, 3. Construct the triangle by the foregoing rules.

PROB. XII.

To reduce a rectilinear figure $ABCDE$, to another equal to it, but with one side less.

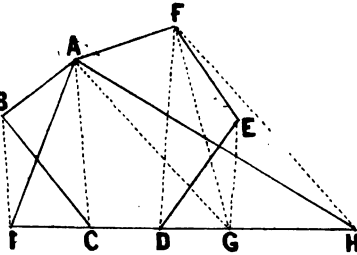
1. Join the extremities E, C , of two sides DE, DC , of the same angle D . 2. From D draw a line DF parallel to EC . 3. Draw EF , and a new polygon $ABFE$ is obtained equal to $ABCDE$, but with one side less.



Corollary. Hence every rectilinear figure may be reduced to a triangle, by reducing it successively to a figure with one side less, until it is brought to one with only three sides.

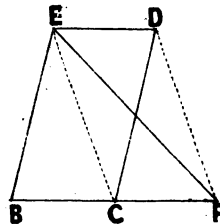
For example; Let it be required to reduce the polygon $ABCDEF$, into a triangle IAH , with its summit at A , in the circumference of the polygon, and its base on the base thereof prolonged.

1. Draw the diagonal DF . 2. Draw EG parallel to DF . 3. Draw FG , which gives us a new polygon, $ABCGF$, with one side less. 4. To reduce $ABCGF$, draw AG , and parallel thereto FH ; then join AH , and a polygon $ABCH$, is obtained equal to the preceding one $ABCGF$. 5. The polygon $ABCH$ having a side AH , which may serve for a side of the triangle, we have only to reduce the part ABC , by drawing AC , and parallel thereto BI ; join AI , and we obtain the required triangle IAH .



Cor. As a triangle may be changed into another of any given height, and with the angle at the base equal to a given angle; if it be required to reduce a polygon to a triangle of a given height, and the angle at the base also given, you must first reduce it into a triangle by this problem, and then change that triangle into one, with the data, as given in the problem last.

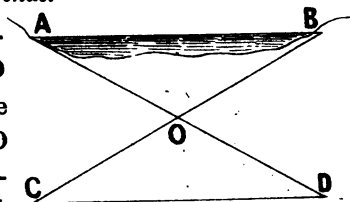
Cor. If the given figure is a parallelogram, draw the diagonal EC , and DF parallel thereto; join EF , and the triangle EBF is equal to the parallelogram $EBCD$.



PROB. XIII.

To find the length of the line AB accessible only at both ends.

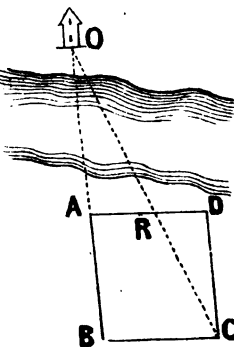
Having fixed on some convenient point O, measure BO and AO; and prolong those lines till $OC = OB$, and $OD = OA$; then the distance between the points D and C will be equal to AB, for the sides of the triangles COD, BOA about the equal angles at O are respectively equal, therefore the third sides CD, BA will also be equal.



PROB. XIV.

To find the distance of an inaccessible object O by means of a rhombus.

With a line or measuring tape whose length is equal to the side of the intended rhombus, lay down one side BA in the direction BO, and let BC another side be in any convenient direction: fasten two ends of two of those lines at C and A; then the other ends (at D) being kept together, and the lines stretched on the ground, those lines AD, CD, will form the other two sides of the rhombus. Set up a mark at R, where OC; AD, intersect; and measure RD; then the sides of the triangles RDC, CBO, being respectively parallel, the triangles will be similar: hence, $RD : DC :: CB : BO$.



Suppose the side of the rhombus is 100 feet, and $RD = 11 \text{ ft. } 7 \text{ in.}$ —then, $11 \frac{7}{12} : 100 :: 100 : 863 \text{ feet nearly} = BO$.

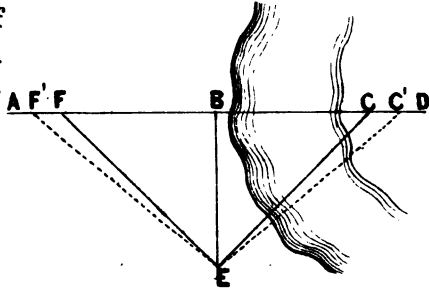
If the ground be nearly level, a rhombus, whose side is 100 feet, will determine distances to the extent of 300 yards within a very few feet of the truth.

PROB. XV.

To find the length of the line AD , inaccessible at the point D .

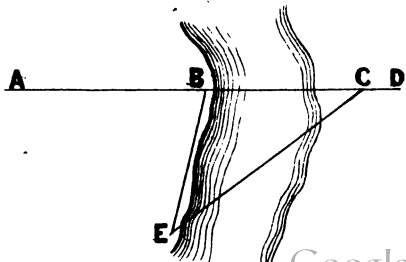
The measurement of the line AD supposed to be run for the determination of a boundary, is stopped at B by a river or other obstacle.

The point F is taken up in the line at about the estimated breadth of the obstacle from B ; and a mark set up at E at right angles to AD from the point B , and about the same distance as BF . The theodolite being adjusted at E , the angle BEC is made equal to BEF , and a mark put up at C in the line AD ; BC is then evidently equal to the measured distance FB .



If the required termination of the line should be at any point C' , its distance from B can be determined by merely reversing the order of the operation, and making the angle BEF' equal to BEC' , the distant BF' being subsequently measured. There is no occasion in either case to *read* the angles. The instrument being levelled and clamped at zero, or any other marked division of the limb, is set on B ; the *upper plate* is then unclamped, and the telescope pointed at F , when being again clamped, it is a second time made to bisect B ; releasing the plate, the telescope is moved towards D till the vernier indicates zero, or whatever number of degrees it was first adjusted to, and the mark at C has then only to be placed in the line AD , and bisected by the intersection of the cross wires of the telescope.

If it is impossible to measure a right angle at B , from some local obstruction, lay off any convenient angle ABE and set up the theodolite at E .



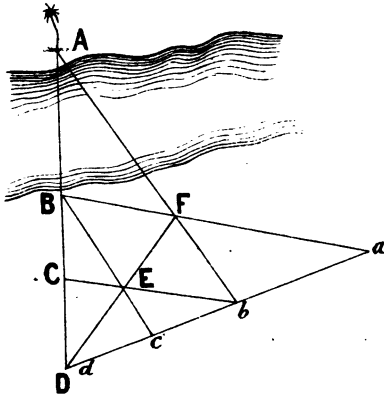
Make the angle BEC equal to *one-half* of ABE , and a mark being set up at C in the prolongation of AB , BC is evidently equal to BE , which must be measured, and which may at the same time be made subservient to the purpose of delineating the boundary of the river.

PROB. XVI.

To find the distance to any inaccessible point, on the other side of a river, without the use of any instrument to measure angles.

Prolong AB to any point D ; making BC equal to CD ; lay off the same distances in any direction $Dc = cb$: — mark the intersection E of the line joining Bc and cb : mark also F the intersection of DE produced, and of Ab — produce Db , and BF , till they meet in a , and

$$\left. \begin{aligned} ab &= AB \\ ac &= AC \\ ad &= AD \end{aligned} \right\}$$

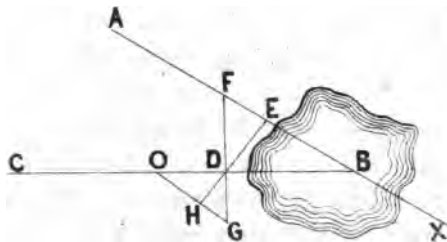


PROB. XVII.

To find the point of intersection of two lines meeting in a lake or river, and the distance DB to the point of meeting.

From any point F on the line AX draw FD , and from any other point E draw ED , produce both these lines to H and G , making the prolongations either equal to the lines them-

selves, or any aliquot part of their length, suppose one-half; join HG , and produce it to O , where it meets the line CB ,

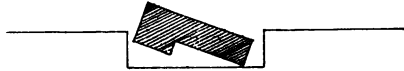


An angle equal to any other angle can also be marked on the ground, with the chain only, by measuring equal distances on the sides containing it, and then taking the length of the chord: the same distances, or aliquot parts thereof, will, of course, measure the same angle.

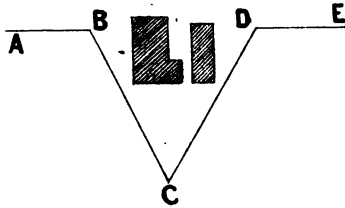
PROB. XX.

To avoid an obstacle such as a house, in your chain line.

The usual way of avoiding an obstacle of only a chain or two in length such as a house, is by turning off to the right or left at right angles till it is passed, and then returning in the same manner to the original line.



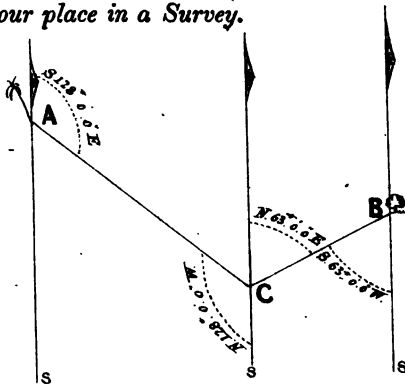
A more convenient method is to measure on a line making an angle of 60° with the original direction a distance sufficient to clear the obstacle, and to return to the line at the same angle, making $CD = BC$ the distance BD is then equal to either of these measured lines.



PROB. XXI.

To find your place in a Survey.

Let A and B be two stations, whose places are fixed, and we want to determine the point C. Take the bearing of A, 128° N.W.: having done which, we know, that C bears from A, 128° S.E. Adjust the protractor at A, by



means of the east and west parallel lines, and lay off 128° S. E., the bearing of C; which point C must, we know, lie somewhere in the line thus obtained. Next, take the bearing of B 63° N. E., and having adjusted the protractor at B, lay off 63° S. W., and where a line drawn from B (to represent this bearing) cuts the line or bearing drawn from A, is the required station C.

The above may be put into a short rule: thus—*To find your station by observations taken to two points already known.* Protract from those points the opposite bearings to what you observe, and their intersection fixes the place sought. For example, if the bearing to a point be 20° N. E., protract from that point 20° S. W., &c.

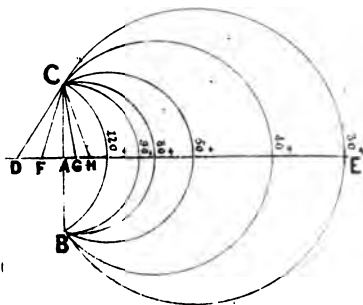
NOTE. That the nearer your two bearings meet at a right angle, the more correct will the station be determined: and also, that when a third fixed point can be seen, a bearing to it will serve to corroborate your other observations; and a point so obtained, namely, by the exact meeting of three bearings, becomes as good as any other point.

The above is a very useful problem—indeed, indispensable when sketching ground and filling in a survey.

PROB. XXII.

To describe on a given line BC, a segment of a circle, capable of containing a given angle.

Bisect BC in A. 2. Through the point of bisection, draw the indefinite right line DE perpendicular to BC. 3. Upon BC, at the point C, make each of the angles DCB, FCB, GCB, HCB, respectively equal to the difference of the angles of the intended segments and 90 degrees: the angle to be formed



on the same side with the segment, if the angle be less than 90; but on the opposite side, if the angle is to be greater than 90 degrees. 4. The points D, F, G, H, where the angular lines CD, CF, CG, CH, intersect the line DE, will be the centres of the intended segments.

Thus, if the intended segment is to contain an angle of 120° make (on the opposite side to which you intend the segment to be described,) the angle DCB equal to 30° , the difference between 90° and 120° ; then on centre D, and radius DC, describe the segment CaB in every part of which, the two points C and B will subtend an angle of 120 degrees.

If we want the segment to contain 80 degrees at O, make the angle BCG, equal 10 degrees, and on the same side of BC as the intended segment; then on G, with radius GC describe segment CgB, in every part of which C and B will subtend an angle of 80 degrees.

NOTE. Two objects can *only* be seen under the *same* angle, from some part of a circle passing through those objects, and the place of observation.

“ If the angle under which those objects appear, be less than 90° , the place of observation will be somewhere in the greater segment, and those objects will be seen under the same angle from every part of the segment.

“ If the angle, under which those objects are seen, be more than 90° , the place of observation will be somewhere in the lesser segment, and those objects will be seen under the same angle from every part of that segment.” Hence, from the situation of three known objects, we are able to determine the station point with accuracy.

●

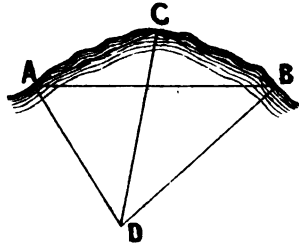
PROB. XXIII.

To determine the position of a point, from whence three points of a triangle can be discovered, whose distances are known.

The point is either without, or within the given triangle, or in the direction of two points of the triangle.

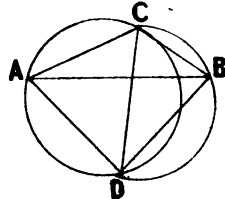
CASE 1st. *When the three given objects form a triangle, and the point or station whose position is required, is without the triangle.*

Example. Suppose we want to determine the position of a rock D , from the shore: the distances of the three points A , C , B , or rather the three sides, AC , CB , AB , of the triangle ABC being given.

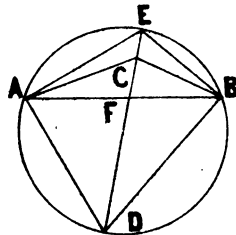


In the first place, the angles ADC , CDB , must be measured by a theodolite; then the situation of the point D may be readily found, either by calculation or construction.

By Construction. Method 1. On AC describe by the preceding problem, a circle capable of containing an angle equal to the angle ADC ; on CB , a segment containing an angle equal to the angle CDB ; and the point of intersection D is the place required.



Another method. Make the angle EBA , equal to the angle ADE , and the angle BAE equal to the angle EDB . Through A , B , and the intersection E , describe a circle $AEBD$; through E , C , draw EC , and produce it to intersect the circle at D ; join AD , BD , and the distances AD , CD , BD , will be the required distances.



By Calculation. In the triangle ABC , are given the three sides, to find the angle BAC . In the triangle AEB , are given the angle BAE , the angles, ABE , AEB , and the side AB , to find AE and BE .

In the triangle AED , we have the side AE , and the angles AED , ADE , and consequently DFA , to find the sides AD , and DE .

The angle ADE , added to the angle AEC , and then taken from 180° , gives the angle DAE . The angle CAE , taken

from the angle DAE, gives the angle CAD, and hence DC. Lastly, the angle AEC, taken from AEB, gives DEB, and consequently, in the triangle DEB, we have EB, the angle DEB, and the angle EDB, to find BD.

In this method, when the angle BDC is less than that of BAC, the point C will be above the point E; but the calculation is so similar to the foregoing, as to require no particular explanation.

When the points E and C fall too nearly together, to produce EC towards D with certainty, the first method of construction is the most accurate.

CASE 2nd. *When the given place or station D, is without the triangle made by the three given objects A, B, C, but in a line with one of the sides produced.*

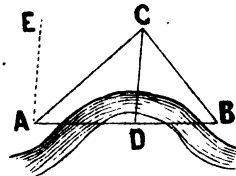
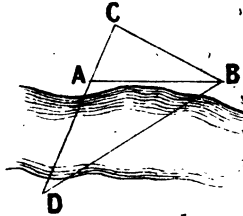
Measure the angle ADB, then the problem may be easily resolved, either by construction or calculation.

By Construction. Subtract the measured angle ADB from the angle CAB, and we obtain the angle ABD; then at B, on the side BA, draw the angle ABD, and it will meet the produced side CA at D; and DA, DC, DB, will be the required distances.

By Calculation. In the triangle ABD, the angle D is obtained by observation, the angle BAD is the supplement of the angle CAB: two angles of the triangle being thus known, the third is also known; we have, consequently, in the triangle ABD, three angles and one side given to find the length of the other two sides, which is readily obtained.

CASE 3rd. *When the station point is in one of the sides of the given triangle.*

By Construction. 1. Measure the angle BDC. 2. Make the angle BAE equal to the observed angle. 3. Draw CD parallel to EA, and D is the station point required.

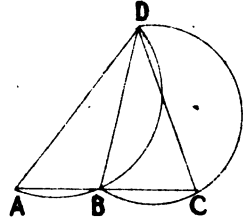


By Calculation. Find the angle B in the triangle ABC, then the angles B and BDC being known, we obtain DCB; and consequently, as Sine of the angle BDC : BQ :: Sine of the angle DCB : BD.

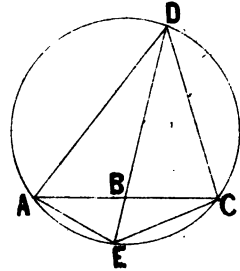
CASE 4th. *When the three given places are in a straight line.*

Example. Being at sea, near a straight shore, I observed three objects, A, B, C, which were truly laid down on my chart; I wished to lay down the place of a sunken rock D; for this purpose the angles ADB, BDC, were observed.

By Construction. Method 1. On AB, describe the segment of a circle, capable of containing the observed angle ADB. On BC describe the segment of a circle, capable of containing the angle BDC; the point D will be at the intersection of the arcs, and by joining DA, DB, DC, the required distances are obtained.



Method 2. Make the angle ACE, equal to ADB, and the angle EAC equal to BDC; and from the point of intersection E, through B, draw a line to ED, to intersect the arc ADC; join A, D, and D, C, and DA, DB, DC, are the required distances.



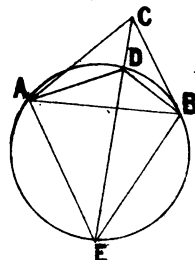
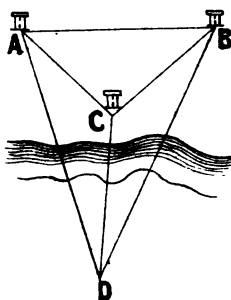
By Calculation. 1. In the triangle CAE, we have all the angles, and the side AC, to find AE. 2. In the triangle ABE, AB, AE, and the included angle are given, to find the angles AEB, ABE. 3. In the triangle BDC the angles BDC and DCB (= ABE) are given, and consequently the angle DCB and the side BC; hence it is easy to obtain DB.

CASE 5th. *When the station falls within the triangle, formed by the three given objects.*

Let ABC represent three towers, whose distance from each other is known; to find the distance from the tower D , measure the angles ADC , BDC , ADB .

By Construction. On two of the given sides AC , AB , describe segments of circles capable of containing the given angles, and the point D of their intersection will be the required place.

Another Method. Make the angle ADE , equal to the angle ADE , and BAE equal to BDE ; describe a circle through the three points A , B , E , and join E , C , by the line EC ; the point D , where EC intersects the circle E , A , D , B , E , will be the required station.



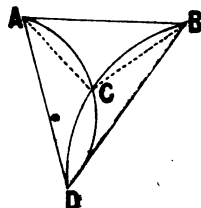
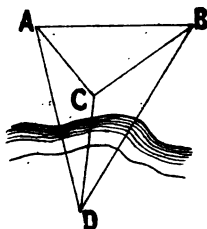
CASE 6th. *When the station point D , falls without the triangle ABC , but the point C falls towards D .*

Let A , B , C , represent three towers, whose respective distances from each other are known; required their distance from the point D .

Measure the angles ADC , BDC , and to prove the truth of the observations, measure also ADB .

By Construction. Method 1. On AC , describe a circle capable of containing the angle BDC , and on AB , one capable of containing the angle ADB , and the point of intersection will be the place required.

Or, it may be constructed by *Method 2, Case 1.* The calculation is upon principles so exactly like those given in that Case that a further detail would be superfluous.

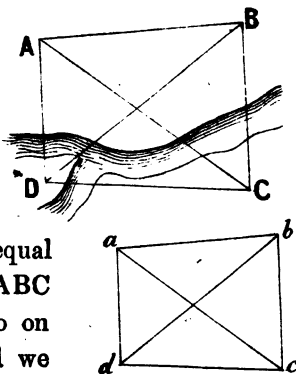


The above instances are sufficient to illustrate this problem, which is extensively useful in Maritime Surveying, to determine the positions of rocks, sands, &c., at a distance from the coast: but the operation may be very much shortened by making use of an instrument called a *station pointer*, which can be set to the observed angles, and then applied to the map or plan, so as to fix the station at once: or, the observed angles may be drawn on transparent tracing paper, and then applied to the plan; which method will be found to answer the purpose.

PROB. XXIV.

The distance of two objects A, B, and the angles ADB, BDC, BCA, being given, to find the distance of the two stations D, C, from the objects A, B.

By Construction. Assume dc any number at pleasure, and make the angles bdc , adc , &c., respectively equal to the angles BDC , ADB , &c., and join ab ; it is plain that this figure must be similar to that required; therefore draw AB , equal to the given distance, and make ABC equal to abc , BAC to bac , and so on respectively; join the points, and we have the distances required.



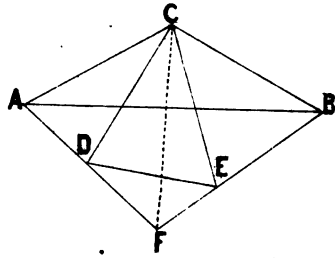
By Calculation. In the triangle adc , we have dc , adc , and acd , to find ad , ac ; in bcd , we have in like manner the three angles, and dc , to find db , bc .

In the triangle adb , we have ad , bd , and the angle adb , to find ab . Hence by the nature of similar figures, as ab to AB :: dc to DC :: ad to AD :: bd to BD :: bc to BC .

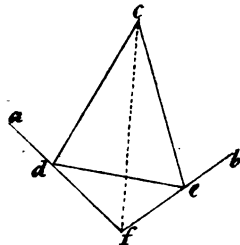
PROB. XXV.

The distances of three objects *A*, *B*, *C*, from each other, and the angles *ADC*, *CDE*, *CED*, *CEB*, being given, to find the sides *AD*, *DC*, *DE*, *EC*, and *EB*.

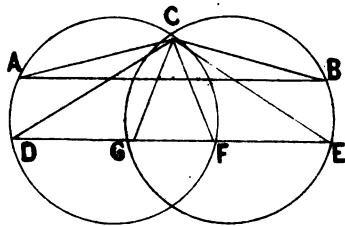
Assume any line *dc*, at pleasure, make the angle *cde* equal to the angle *CDE*, and the angle *ced* equal to the angle *CED*; also the angle *cda* equal to the angle *CDA*, and the angle *ceb* equal to the angle *CEB*; produce *ad*, *be*, to intersect each other at *f*, and join *cf*.



It is evident that the figures *cdfe*, *CDFE*, are similar; therefore, on *AC*, describe a segment of a circle, capable of containing an angle *AFC* equal to *afc*; and on *CB* a segment capable of containing an angle *CFB*, equal to the angle *fcB*; from the point of intersection *F*, draw *FA*, *FB*, *FC*; make the angle *FCD* equal to the angle *fed*, and *FCE* equal to the angle *fec*, which completes the construction; then by assuming *de* equal to any number, the rest may be found as before.



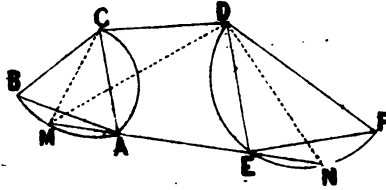
This method fails when *AB* is parallel to *DE*, therefore, having described the segments *ADC*, *BEC*, draw *CF*, to cut off a segment equal to the angle *CDF*, and the right line *CG*, to cut off a segment equal to the angle *CEG*; *GF* will be in the right line *DE*; therefore, join *GF* and produce the line each way, till it intersects the segments, and the points *D*, *E*, will be the stations required.



PROB. XXVI.

Four points B, C, D, F , or the four sides of a quadrilateral figure, with its angles being given, and the angles BAC, BAE, AED, DEF , known by observation, to find the station points A and E , and consequently, the length of the lines AB, AC, ED, EF .

By Construction. 1. On BC describe the segment of a circle, to contain an angle equal to BAC . 2. From C draw the chord CM , so that the angle BCM may be equal to the supplement of the angle BAE . 3. On DF describe the segment of a circle capable of containing an angle equal to DEF ; join MN , cutting the two circles at A and E , the required points.



By Calculation. In the triangle BCM , the angle BCM , (the supplement of BAE), and the angle BMC , ($= BAC$), and the side BC are given, whence it is easy to find MC . In the same manner, DN in the triangle DNF may be found; but the angle MCD , ($= BCD - \text{angle } BCM$) is known with the sides MC, CD ; consequently, MD , and the angle MDC , will be readily found.

The angle MDN , ($= \text{angle } CDF - CDM - FDN$) and MD, DN , are known; whence we find MN , and the angles DMN, DNM .

The angle CMA , ($= DMC + DMN$), the angle MAC , ($= MAB$ added to BAC), and the side MC are given; therefore, by calculation, MA , and AC will also be known.

In the triangle EDN , the side DN , and the angles E and N are given: whence we find EN, ED , and, consequently, AE equals $MN - MA - EN$.

In the triangle ABC , the angle A , with its sides BC, AC , are known; hence AB , and the angle BCA , are found.

In the triangle EFD, the angle E, with the sides ED, DF, being known, EF and the angle EDF can be found.

Lastly, in the triangle ACD, the angle ACD, ($=$ BCD, $-$ BCA,) and AC, CD, are given; hence AD is found, as in the same manner EC in the triangle ECD.

NOTE.—In this Problem, and in Problems XXIV and XXV, if the two stations fall in a right line with either of the given objects, the problem is indeterminate. As to the other cases of this problem, they fall in with what has already been said.

The solution of this problem is general, and may be used for the two preceding ones; for suppose CD the same point in the last figure, it gives the solution of Problem XXV., but if B, C, be supposed the same points D, F, we obtain the solution of Problem XXIV.

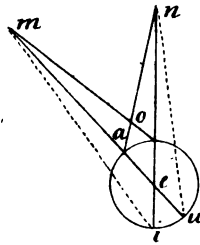
PROB. XXVII.

To reduce angles to the centre of the station.

In surveys of kingdoms, provinces, counties, &c., where signals, churches, &c., at a distance, are used for points of observation, it very often happens that the instrument cannot be placed exactly at the centre of the signal or mark of observation; consequently, the angle observed will be either greater, less, or equal to that which would have been found at the centre. This problem shows how to reduce them to the centre; the correction seldom amounts to more than a few seconds, and is, therefore, seldom considered, unless where great accuracy is required.

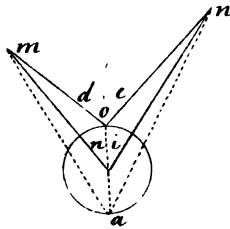
The observer may be considered in three different positions with respect to the centre and the objects; for he is either in a line with the centre, and one of these objects, or in an intermediate one, that is, a line from this centre to the observer produced, would pass between the objects; or he is in an oblique direction, so that a line from the centre to him would pass without the objects.

CASE 1st. Where the observer is at o , between the centre and one of the objects, the exterior angle mon , is greater than the angle men , at the centre, by the angle emo ; therefore, taking emo from the observed angle, we have that at the centre.

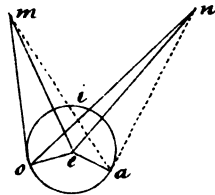


If the observer is at a the exterior angle man , is greater than that of men , at the centre, by the value of n ; therefore, take this from the centre. But if the observer is further from the objects than the centre, as at i , the observed angle min , is less than that at the centre men , by the angle m ; therefore, by adding m to the observed angle, we obtain the angle men , at the centre. In the same manner, if the observer is at u , we should add the angle n to the observed angle mun , in order to have the angle men , at the centre.

CASE 2nd. When the observer is at o , draw ao , and the interior angle d exceeds the angle u at the centre by the angle m , and the exterior angle c exceeds the angle at the centre a , by the angle n ; therefore, mon exceeds the angle at the centre, by the value of the two angles m and n ; these, therefore, must be subtracted from it, to obtain the central angle. On the contrary, if the observer is at a , the two angles m and n must be added to the observed angle.



CASE 3rd. When the observer is at o , having measured the angles mon , moe , the angle i is exterior to the two triangles moi , nei ; therefore, to render men , equal to min , we must add the angle n ; and to render the exterior angle min , equal to the observed angle mon , we must take away the angle m ; therefore, adding m to the observed angle, and subtracting n from the total, we obtain the central angle m or n .



From what has been said, it is clear, that in the first case, we are to add or subtract from the observed angles, that of the angles m or n , which is not in the direction of the observer.

In the second case, we have either to subtract or add the two angles m or n .

In the third case, we add to the observed angle, that of the two m or n , which is of the same side with the observer, and subtract the other.

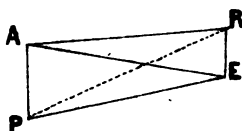
To know the position of the observer, care must be taken to measure the distance of the instrument from the centre, and the angles this centre makes with the objects.

An inspection of the figures is sufficient to show how the value of the angles m , n , may be obtained. Thus, in the triangle *moe*, we have the angle at o , the distance oe , and the distances em , om , (which are considered as equal,) given.

PROB. XXVIII.

To reduce triangles from one plane to another.

After the reduction of the observed angles to the centre of each respective station, it is generally necessary to reduce the parts of one, or of several triangles to the same level.



Case 1. Let us suppose the three points A , P , E , to be equally distant from the centre of the earth, and that the point R is higher than these points by the distance or quantity RE ; now it is required to reduce the triangle APR to that of APE .

By the following rule, we may reduce the angles RAP , RPA , which have their summits in the plane of reduction, to the angles EPA , EAP .

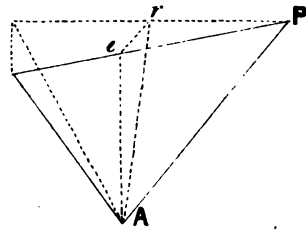
Rule. The co-sine of the reduced angle is equal to the co-sine of the observed angle, divided by the co-sine of the angle of elevation.

These two angles being known, the third angle E is consequently known; we shall, however, give a rule for finding AEP, independent of the other two.

Rule. The co-sine of the reduced angle is equal to the co-sine of the observed angle, lessened by the rectangle of the sines the angles of elevation, divided by the rectangle of the co-sine of the same angles.

The reduction of the sides can be no difficulty.

Case 2. Let ARr, be the \mathbf{R} triangle to be reduced to the plane AEE, the points E, e, of the vertical lines RE, re, being supposed equally distant from the centre of the earth.

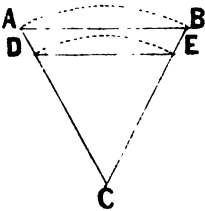


Prolong the plane AEE, to P, that is, till it meets the line Rr, produced to P; and the value of EAe, will be found by this formula.

Tangent $\frac{1}{2}$ (PAR + .PAr) = tangent $\frac{1}{2}$ RA r \times tangent $\frac{1}{2}$ (RAE + rAe). Knowing the half sum and half tangent $\frac{1}{2}$ (RAE - rAe)

difference of PAR, and PAr, we obtain the value of each of the angles; the value of PAE, and PAe, may be then obtained by the first of the two preceding rules, and the difference between them is the angle sought.

Let C be the centre of the earth, A and B the side of a triangle reduced



to a common horizon by the preceding methods; if it be required to reduce this to the plane DE, as these planes are parallel, the angles will remain the same; therefore, the sides only are to be reduced, the mode of performing which is evident from the figure.

PROB. XXIX.

Method of carrying on a triangulation for any survey, whether the object be to find the distance between two given points or for any other purpose whatever.

Let AB be a base of 2 miles, or 3520 yards; and suppose poles or flag-staves are set up at the stations A, B, C, D, G; and that the angles at those stations, taken with a theodolite, are the following:

$$C A B = 64^{\circ} 29'$$

$$C B A = 75 \ 15$$

$$A C B = 40 \ 18$$

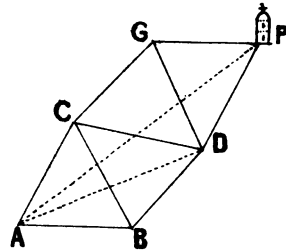
$$\text{Sum} = 180 \ 02$$

$$B C D = 53 \ 41$$

$$C B D = 64 \ 08$$

$$B D C = 62 \ 14$$

$$\text{Sum} = 180 \ 03$$



$$D C G = 73^{\circ} 58'$$

$$C D G = 51 \ 27$$

$$C G D = 54 \ 33$$

$$\text{Sum} = 179 \ 58$$

$$D G P = 71 \ 07$$

$$G D P = 46 \ 51$$

It is required to find the distance of the Spire P from the Station A.

The error in the sum of the three observed angles of the first triangle is, 2'; in the second, 3'; and in the third, 2'. The angle at P, in the fourth triangle, is supplemental.

No certain rule can be given for correcting the observed angles; this must be left to the judgment of the observer, who, from circumstances, will seldom be at a loss to point out where the greatest uncertainty lies. To make the calculation, however, we will suppose the corrected angles are

$$C A B = 64^{\circ} 28'$$

$$C B A = 75 \ 14$$

$$A C B = 40 \ 18$$

$$\text{Sum} = 180 \ 00$$

$$D C G = 73^{\circ} 58'$$

$$C D G = 51 \ 28$$

$$C G D = 54 \ 34$$

$$\text{Sum} = 180 \ 00$$

$$\begin{aligned} B C D &= 53^{\circ} 40' \\ C B D &= 64 07 \\ B D C &= 62 13 \end{aligned}$$

$$\begin{aligned} D G P &= 71^{\circ} 07' \\ G D P &= 46 51 \\ G P D &= 62 02 \end{aligned}$$

$$\text{Sum} = 180 00$$

$$\text{Sum} = 180 00$$

Then,

As $\angle A C B$ or $40^{\circ} 18'$...	Sine	9.810763	
: A B ,, 3520 ...	Log.	3.546543	
:: $\angle C A B$,, $64^{\circ} 28'$...	Sine	9.955368	
		<u>13.501911</u>	
: C B ,, 4910.7 ...	Log.	3.691148	= CB or 4910.7
Add $\angle D C B$,, $53^{\circ} 40'$...	Sine	9.906111	
		<u>13.597259</u>	
Dedt. $\angle B D C$,, $62^{\circ} 13'$...	Sine	9.946804	
	Log.	3.650455	= BD or 4471.5
Add $\angle C B D$,, $64^{\circ} 07'$...	Sine	9.954090	
		<u>13.604545</u>	
Dedt. $\angle D C B$,, $53^{\circ} 40'$...	Sine	9.906111	
	Log.	3.698434	= CD or 4993.8
Add $\angle D C G$,, $73^{\circ} 58'$...	Sine	9.982769	
		<u>13.681203</u>	
Dedt. $\angle C G D$,, $54^{\circ} 34'$...	Sine	9.911046	
	Log.	3.770157	= DG or 5890.6
Add $\angle D G P$,, $71^{\circ} 07'$...	Sine	9.975974	
		<u>13.746131</u>	
Dedt. $\angle D P G$,, $62^{\circ} 02'$...	Sine	9.946069	
	Log.	3.800062	= DP or 6310.5

Now, from the sides BA, BD, and the included angle ABD = $139^{\circ} 21'$, we get the angle BDA = $17^{\circ} 48'$ and AD = 7501.1 yards.

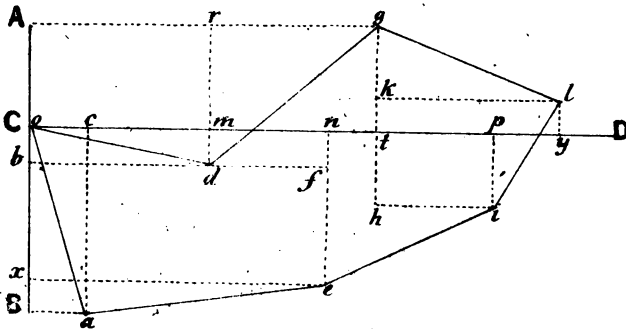
And, if BDA be taken from $160^{\circ} 32'$, the angle BDP, there remains $142^{\circ} 44'$ the angle ADP, which, with the including sides AD = 7504.1, and DP = 6310.5, will give the distance from P to A = 13093 yards.

When triangles are carried on from the original base in all directions, the distances towards the extremities may, in some respect, be verified by independent calculation.

PROB. XXX.

To refer a series of triangles to a Meridian line, and another line Perpendicular to it.

This method should be adopted wherever extreme accuracy is required, for whatever care is taken to protract a series of triangles, the protractor, the points of the compasses, the thickness of the line, the inequality of the paper, &c. will produce in the fixing of the points of a triangle, an error, which, though small at first, will have its influence on those that succeed, and become very sensible, in proportion as the number of triangles is augmented.



Let AB, be the Meridian, CD, the Perpendicular, and the triangles *oad*, *dae*, *deg*, *egi*, *gil*, those that have been observed ; from the point *o*, (which is always supposed to be on a meridian, or whose relation to a meridian is known) observe the angle *Boa*, to know how much the point *a* declines from the meridian.

In the right-angled triangle, *oBa*, we have the angle *Boa*

and the right angle oBa , and consequently the angle oaB together with the side oa , to find oB , and Ba .

For the point d , add the angle Boa , to the observed angle aod , for the angle dob , or its equal odm , and the complement is the angle mod , whence as before, to find om , and md .

For the point g , add the angles, mdo , oda , ade , and edg , which subtract from 360° , to obtain the angle gdr , of the right-angled triangle grd ; hence we also readily, as in the preceding triangles, obtain $rg = mt$, which added to mo , gives to the distance from the meridian. Then we obtain rd , from which taking dm , we obtain $rm = gt$, the distance from the perpendicular.

For the point e , take the right angle rdf from the two angles rdg , gde , and the remainder is the angle fde of the right-angled triangle dfe ; hence we obtain fed and df , which added to db , gives $bf = xe$, the distance from the meridian; from the same right-angled triangle we obtain fe , which added to $fn = dm$, gives en , the distance from the perpendicular.

For the point i , add together the angles rgd , dge , egi , and from the sum subtract the right angle rgh , and we obtain the angle ghi , of the right-angled triangle hgi , and consequently the angle i ; hence also we get $hi = tp$, which added to to , gives op , distance from the meridian, and gh , from which subtracting gt , we obtain $th = pi$, distance from the perpendicular.

For the point l , the angle ghi , added to the angle lgi , gives the angle lgk of the right-angled triangle gkl , and of course the angle glk , whence we obtain kl , or ty , which added to to , gives oy , distance from the meridian; hence we also obtain gh , which taken from gt , gives $kt = ly$, distance from the perpendicular.

If, before the operation, no fixed meridian was given, one may be assumed as near as possible to the point o ; for the error in its position will not at all influence the respective position of the triangles.

PROB. XXXI.

A Map with its Area being given, and its Scale omitted to be either drawn or mentioned; to find the Scale.

Cast up the map by any scale whatsoever, and it will be,
As the Area given.

: *The Square of the scale by which cast up*

:: *The given Area of the Map*

: *The Square of the scale by which it was laid down.*

The Square root of which will give the-Scale.

EXAMPLE.

A map whose area is 126 Ac. 3 Rds. 16 Per. being given and its scale omitted to be either drawn or mentioned; to find the scale.

Suppose the map was cast up by a scale of 20 Perches to an inch, and the content thereby produced be 31 Ac. 2 Rds. 34 Per.

Then,

As the Area given or 81 Ac. 2 Rds. 34 Per. = 5074 Per.

: *The Square of the scale by which it was* } 400
cast up, that is to 20 × 20 = }

:: *The given Area of the map 126 Ac. 3 Rds. 16 Per. = 20296 Per.*

: *The Square of the scale by which it was laid down.*

Or, as 5074 : 400 :: 20296 : 1600 the Square of the required scale, the Square root of which = 40.

The map was therefore laid down by a scale of 40 Perches to an inch.

PROB. XXXII.

To find the true Area of a Survey, though it be taken by a Chain that is too long or too short.

Let the map be constructed, and its area found as if the chain was of a true length, and it will be

As the Square of the true chain,

: *The area of the map*

- ∴ *The Square of the chain surveyed by*
 ∴ *The true Area of the map.*

EXAMPLE.

If a Survey be taken with a chain which is 3 inches too long; or with one whose length is 42 Feet 3 Inches, and the map thereof be found to contain 920 Ac. 2 Rds. 20 Per. Required the true area.

As the Square of 42 Ft. 0 In. = the Square of 504 inches
 = 254016

∴ *The area of the map 920 Ac. 1 Rd. 20 Per. =*
 147260 Per.

∴ *The Square of 42 Ft. 3 In. = the Square of 507 inches =* 257049

∴ *The true area.*

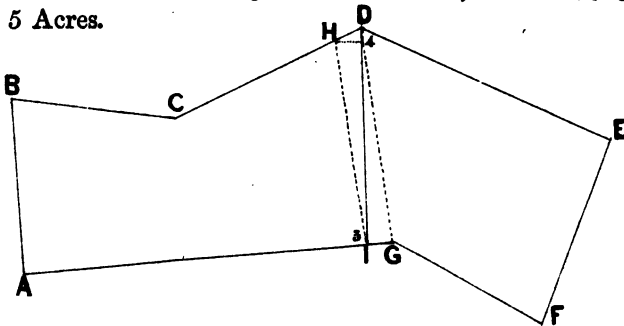
Ac. Rd. Per.

or, 254016 : 147260 ∴ 257049 : 149019 = 931 ,, 1 ,, 19

PROB. XXXIII.

How to divide land, or to take off any given part from a Map.

Let ABCD, &c. be a map of ground, containing 11 Acres, it is required to cut off a piece as DEFGID, that shall contain 5 Acres.



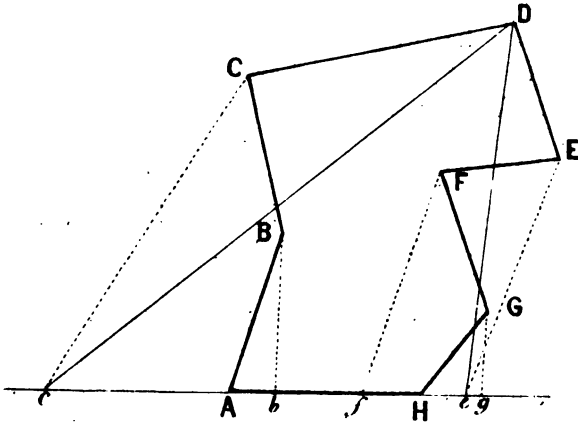
Join any two opposite stations as D and G, with the line DG, (which we may nearly judge to be the partition line) and find the Area of the part DEFG, which suppose may

want 3 Rds. 20 Per. of the quantity we would cut off: Measure the line DG, which suppose to be 70 Perches. Divide 3 Rds. 20 Per. or 140 Per. by 35, the half of DG, and the quotient 4 will be a perpendicular for a triangle whose base is 70, and the Area 140 Per. Let HI be drawn parallel to DG, at the distance of the perpendicular 4, and from 3 where it cuts the boundary, draw a line to D, and that line DI will be the division line.

PROB. XXXIV.

To determine the Area of a piece of ground, having the map given, by reducing it to one triangle equal thereto, and thence finding its Area.

Let ABCDEFGHA be a map which we would reduce to one triangle equal thereto.



Produce any line of the map, as AH, both ways: lay the edge of a parallel ruler from A to C, having B above it: hold the other side of the ruler fast; open until the same edge touches B, and with a protracting pin, mark the point *b* on the produced line: lay the edge of the ruler from *b* to D,

O

having C above it: hold the other side fast, open until the same edge touches C, and mark the point *c*, on the produced line. A line drawn from *c* to D will take in as much as it leaves out of the map.

Again, lay the edge of the ruler from H to F, having G above it, keep the other side fast, open until the same edge touches G, and mark the point *g*, on the produced line: lay the edge of the ruler from *g* to E, having F above it, keep the other side fast, open until the same edge touches F, and mark the point *f*, on the produced line. Lay the edge of the ruler from *f* to D, having E above it, keep the other side fast, open until the same edge touches E, and mark the point *e*, on the produced line. A line drawn from D to *e*, will take in as much as it leaves out. Thus we have the triangle *cDe*, equal to the irregular polygon ABCDEFGHA.

If when the ruler's edge be applied to the points A and C, the point B falls under the ruler, hold that side next the said points fast, and draw back the other to any convenient distance; then hold this last side fast, and draw back the former edge to B, and mark *b*, on the produced line; and thus a parallel may be drawn to any point under the ruler, as well as if it were above it. It is best to keep the point of the protracting pin in the last point in the extended line, until the edge of the ruler is laid to the next station, or one point may be mistaken for another.

This may also be performed with a scale, or ruler, which has a thin sloped edge, called a fiducial edge and a fine pointed pair of compasses. Thus,

Lay that edge on the points A and C, take the distance from the point B to the edge of the scale, so as it may only touch it, in the same manner as you take the perpendicular of a triangle; carry that distance down by the edge of the scale parallel to it, to *b*, and there describe an arc on the point *b*, and if it just touches the ruler's edge, the point *b* is in the true place of the

extended line. Then lay the fiducial edge of the scale from b to D , and take a distance from C , that will just touch the edge of the scale; carry that distance along the edge, until the point which was in C , cuts the produced line in c ; keep that point in c , and describe an arc, and if it just touches the ruler's edge, the point c is in the true place of the extended line. Draw a line from c to D , and it will take in and leave out equally. In like manner the other side of the figure may be balanced by the line eD .

Let the point of the compasses be kept to the last point of the extended line, until the scale is laid from it to the next station, to prevent mistakes from the number of points.

That the triangle cDe , is equal to the right-lined figure $ABCDEFGH$, will be evident from Problems 13, 14. Chap. 3. For if a line were drawn from b to C , it will give and take equally, and then the figure $bCDEFGH$, will be equal to the map. Thus the figure is lessened by one side, and the next balance line will lessen it by two, and so on, and will give and take equally. In the same manner an equality will arise on the other side.

The area of the triangle is easily obtained and thus we have the area of the map.

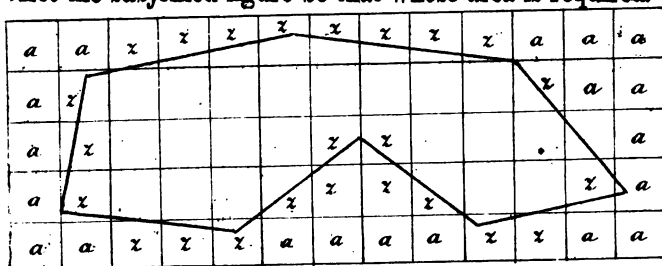
It is best to extend one of the shortest lines of the polygon, because if a very long line be produced, the triangle will have one angle very obtuse, and consequently the other two very acute; in which case it will not be easy to determine exactly the length of the longest side, or the points where the balancing lines cut the extended one.

This method will be found very useful and ready in small enclosures, as well as very exact; it may be also used in large ones, but greater care must be taken of the points on the extended line, which will be crowded, as well as of not missing a station.

PROB. XXXV.

To determine the Area of a piece of ground, having the Map given, by weight.

Let the subjoined figure be that whose area is required.



Let parallels be drawn at half an inch asunder, and others at right angles to them at a like distance; each square will then be a quarter of a square inch in area.

With a penknife, cut away all the squares marked *a*, which the boundary of the map does not reach, then all the whole squares contained within the body of the map, and the squares which the boundary passes through and which are marked *z*, *z*, *z*, &c., will remain.

Add the number of whole squares in the body of the map, and those marked *z*, together, which number note down; then find with grains and tenths of a grain, the weight of the paper. Call the number of squares, first area, and their weight in grains and parts, their first weight.

Then cut the map close by the boundary and weigh it in grains and decimals of a grain, as before. Then say, as the first weight, is to the first area, so is the second weight to the second area, which gives the area of the map in squares, and decimals of a square. Then by knowing by what scale it was laid down, the area of each square is known and consequently the area of the whole map.

The state of the Atmosphere has a very sensible effect on this operation. The weightment should be made with as delicate scales as possible, and the mean of two, or more trials adopted.

Part III.

ON SURVEYING INSTRUMENTS.

CHAPTER I.

OF THE CHAIN.

GUNTER'S Chain is the measure adopted in the Indian Revenue Surveys, but a description of it having been given under the head of "Areas," it is unnecessary to repeat it here.

The length of a straight line must be found mechanically by the Chain, and it is the most difficult operation in Surveying. The Surveyor therefore cannot be too careful in guarding against, rectifying, or making allowances for every possible error, for on the exactness of this mensuration, the correctness of his operations depend.

The Chain, however useful and necessary, is liable to many errors—1st, in itself,—2ndly, in the method of using it,—and 3rdly, in the uncertainty of pitching the arrows, every possible precaution must therefore be used.

If the Chain be stretched too tight, the rings will give, the arrows incline and the measured line will be shorter than it really is ; on the other hand, if it be not drawn sufficiently tight, the measure obtained will be too long.

If the Chain is a new one, it should invariably be measured *daily* until it has stretched to its utmost, if an old one, and which a Surveyor will find by experience, to be always preferable, once in every three or four days is sufficient. A careful and correct Surveyor, will, however compare it daily.

Chains have been known to stretch as much as 3 inches in a day's work, this though trifling in one Chain, would be found of material consequence, after measuring 400 or 500 Chains during the day, amounting as such an error would, to nearly one Chain and a half in the whole distance measured. The rectifying of such errors in the Chain measurements is easily done by a calculation from Table A, (*vide* Appendix) but a correct Chain saves much trouble.

In the event of a Chain having lengthened, the correction, whatever it may be, to the Chain lines, must be made by addition, and *vice versa*, if the Chain is short, by subtraction of the quantity required to rectify the error. Thus,

Supposing a Chain to have stretched 1 inch, a correction of one link additive in every 8 Chains measured, would be necessary to give the true length of any line measured with that Chain. Taking the measured line to be 64 Chains the correct length of the line would be 64 Chains + 64 Inches or 64 Chains, 8 Links, and the reverse 64 Chains — 64 Inches or 63 Chains, 92 Links, should the Chain be 1 Inch too short; such a correction is sufficient for all practical purposes.

It is a common practice, to allow Chainmen too much latitude in measuring lines, *i. e.*, the Surveyor is satisfied to come up at the end of the line measured, count the number of links up to the station, depending entirely on the rear Chainman, for a correct account of the number of Chains measured. This, even were the account of Chains correct, (which is always doubtful) can never be a satisfactorily measured line. Unless the Surveyor follows in the rear of his Chainmen, and keeps a continued watch on them, the probabilities are, that his work will have to be measured over again.

A Surveyor should accustom himself to follow his rear Chainman and satisfy himself, as he is progressing, that he is measuring straight. To ensure the Chainmen proceeding in as straight a line as possible, it is always well, for the *leading* Chainman to check the direction of the *rear* Chainman, by keep-

ing the latter, and the back station (on which there is invariably a flag) in a straight line with himself. The *rear* Chainman does this, as he directs the *leading* one, with the forward station, and thus by a mutual check, great accuracy is obtained.

Eleven arrows should be used, instead of ten as is generally the custom, for in the latter case, when the Chain arrives at the end of the tenth arrow, thus denoting 10 Chains as measured, the Chain is stopped and liable to be shifted; whereas with eleven arrows, one arrow always remains a fixture in the ground and is never brought into the account, thus preventing the possibility of the Chain being shifted whilst the other ten arrows are being taken to the leading Chainman.

It is usual to have steel rods of 6 or 11 feet, to test the Chains with, the former are the most portable, and the Superintendent of a Survey cannot be too careful in ascertaining that these rods are supplied of the exact lengths, and also, in insisting on their use.

Two rods of 6 feet each, are sufficient for a Survey party, and the method of using them is, to stretch the Chain pretty tight on a level piece of ground, fixing two stout pins made for the purpose, at each end in the handles of the Chain, then, by laying down the two rods from one end, keeping the second stationary, and taking up the first, and placing it beyond the second, then keeping that stationary and taking up the second, and placing it beyond the third and so on, until arrived at the end of the Chain, when eleven rods thus measured should be its length.

Experience, however, and the disagreeable necessity of doing work twice over, which is always irksome, can alone teach a Surveyor the necessity of measuring lines correctly, and of keeping a constant watchfulness over the length of his Chain.

Directions for using the Chain. Flags are first to be set up at the places whose distances are to be obtained; the place where the measurement is commenced may be called the *first* station, and that measured to, the *second* station. Two men hold the Chain, one at each end; the foremost or leader is

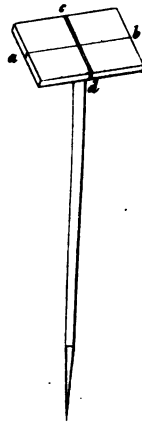
provided with eleven arrows, and a small hammer. These arrows are made of iron about one-third of an inch square pointed at one end, with a loose ring on the head, for the purpose of hanging in a hook suspended from the girdle of the Chainman. On the Chain being stretched in the direction of the *second* station the leader hammers an arrow firmly into the ground, the rear Chainman holding the other end at the *first* station; he then proceeds on in the direction of the *second* station, until the rear Chainman has arrived at the first arrow, when the latter directs the former in a line with the *first* station, and a second arrow is firmly driven in; the rear Chainman then takes up the first arrow, counts one Chain as measured, and proceeds on until the eleven arrows are expended, one of which remaining in the ground, the other ten are sent on to the leading Chainman. The exchange of the arrows is always notified by the rear Chainman calling out with a loud voice, so many Tens. The Surveyor here marks in his Field Book, that one change has been made, or 10 Chains or 1000 Links measured. The Chainmen then proceed onwards, until another change has been made, and entered, and so on, marking every change until the *second* station is arrived at, when the number of arrows in the hand of the rear Chainman will denote the number of Chains, which, together with the odd links and the number of changes that may have been made between the two stations, will make up the entire length of the line.

OF THE "CROSS STAFF" AND "OFFSET ROD."

When the boundary of a Survey has turns and bends in it, as is generally the case, it is not necessary to measure round every such turn and bend. The best and most usual way, is to proceed in a straight line from one principal corner to another, and when opposite to any bend in the boundary to measure the rectangular distance, termed the *Offset* from the chain line to the bend, noting the same,

together with the distance on the Chain line from whence such Offset was made. These Offsets are generally measured with an Offset Staff or Rod of ten or twenty links in length, ten or five of them making one Chain, and as they are all rectangular with the Chain line, they either form triangles or trapezea, of which the distance on the Chain line is the base and the Offset the perpendicular, to be calculated by the rules given under the head of "Areas," and added or deducted according as they are to the right or left of the Chain line. Great care is required on the part of the Surveyor in measuring Offsets, for unless the Offset is taken at right angles with the Chain line, the perpendicular measured for determining its area will be too long, and a correct result will not be obtained.

A very convenient instrument called the "Cross-Staff," and which can be made up by any Bazar Carpenter, is used for the purpose of taking Offsets. It consists of a piece of wood, about 6 inches square and an inch and a half in thickness, fixed on the end of a staff about 5 feet in length, with an iron spike at the end, for the convenience of planting it in the ground. The square piece on the top has two slits *ab* and *cd* in it, about half an inch deep, at right angles with each other,



made with a common saw. This instrument being placed any where on the Chain line, if one slit is directed to the forward or back station, the other will of course give the perpendicular to the Chain line. A well practised Surveyor can, however, generally tell a right angle for an Offset, without the assistance of this instrument.

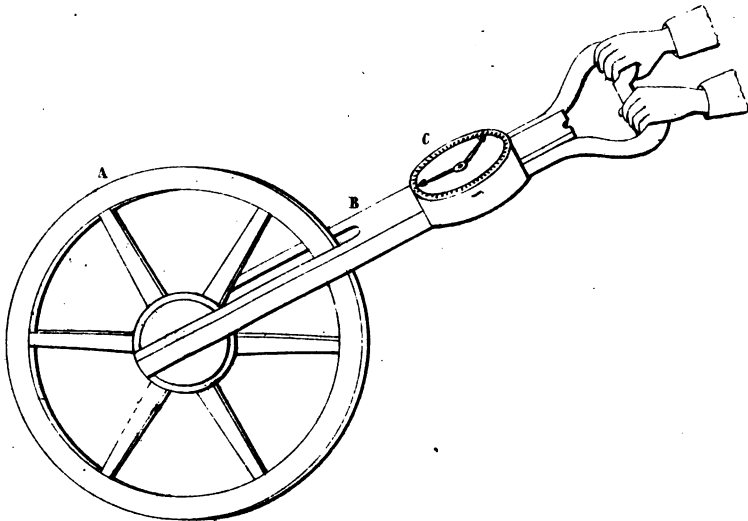
The best method of measuring Offsets, is, for the Offset man to walk along the boundary, and to give a signal to the Chain party, whenever he comes to a bend or corner, the Surveyor then places himself on the Chain line in a rectangular

position with the Offset man, when the latter, measuring down towards him, gives in the length of the Offset in rods, and returns immediately to the boundary to take up the next bend. A good Offset man should never be taken off his work, for by constant practice he knows exactly when and where an Offset is required.

ON THE PERAMBULATOR.

THIS instrument is very useful for measuring roads, level plains, and every thing where expedition is required. It gives however a measure somewhat too long in going over uneven surfaces, which is one of its principal objections, and is therefore only applicable to road and route Surveys, where great accuracy is not essential.

The following figure represents the Perambulator, which consists of a wheel of wood A, shod or lined with iron to prevent the wear; a short axis is fixed to this wheel, which communicates motion by a long pinion fixed in one of the sides of the carriage B, to the wheel-work C, included in the box-part of the instrument. For portability the wheel A is separable.



In this instrument, the circumference of the wheel A, is 8 feet 3 inches, or half a pole; one revolution of this wheel turns a single-threaded worm once round; the worm takes into a wheel of 80 teeth, and turns it once round in 80 revolutions; on the socket of this wheel is fixed an index, which makes one revolution in 40 poles, or one furlong; on the axis of this worm is fixed another worm with a single thread, that takes into a wheel of 40 teeth; on the axis of this wheel is another worm with a single thread, turning about a wheel of 160 teeth, whose socket carries an index that makes one revolution in 80 furlongs, or 10 miles. On the dial plate, there are three graduated circles, the outermost is divided into 220 parts, or the yards in a furlong: the next into 40 parts, the number of poles in a furlong; the third into 80 parts, the number of furlongs in 10 miles, every mile being distinguished by its proper Roman figure.



The instruments generally made in England have been found unsuited to the wants of Indian service: the following describe those in general use in India.

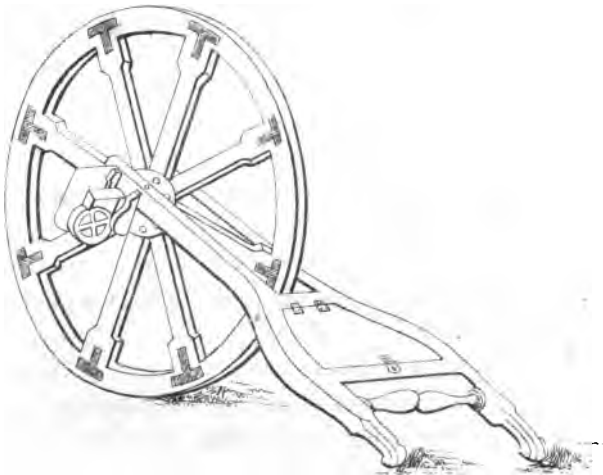
The Madras Pattern 8-Mile Perambulator.—The 8-mile Madras Pattern Perambulator, on the adjoining page, consists of a wheel 20 feet in circumference, having a brass plate 7 inches in diameter on each side of its centre for connecting the spokes. On one side, the plate A is graduated, in feet and inches from 1 to 20 feet, in three circles, one within the other, each circle containing $6\frac{2}{3}$ feet. An axle B, passes through the centre of these plates to which is attached an endless screw D, playing in the teeth of two circular brass plates $8\frac{1}{2}$ inches in diameter suspended from the axle, one plate having 66, and the other 64 teeth. The front plate is graduated to 220 yards, and the back plate to furlongs and miles,

which are read off through the openings G, G, in the front plate, the index E being turned down on the plate to denote the yards, and the index H, with adjusting weight W, denoting the feet and inches on the plate A, attached to the wheel. The axle B is furnished at both ends with a revolving wooden handle C, C.

This instrument is best adapted for road work: to a Surveyor, it is of little use, its great height rendering it difficult to manage in a high wind, and requiring two men to work it. The only advantage it has over other instruments of the kind is, that it bears its own weight, and the handles being about the height of a man's chest, it is only necessary to keep the wheel steady, when the least pressure sets it in motion.

Lieutenant Colonel Everest's Pattern 6-Mile Perambulator.—

This instrument consists of a wheel, the circumference of which is 107.39 inches. The spokes are connected by two strong brass plates secured with bolts, the centre of these



plates having a square hole, through which the axle passes. It has shafts and handles similar to the one described at page 106, but somewhat different in construction, the shafts being made of well-seasoned wood, and the handles like those of a wheelbarrow. The machinery is extremely simple, consisting only of an endless screw, with two brass plates attached, the diameters of which are $3\frac{4}{10}$ inches, the upper one containing 59, and the lower 60 skew-bevelled teeth; the upper plate is divided into 100 parts, the wheel being bevelled inside to admit of every 10th part bisecting the surface of the lower wheel graduations; the lower plate being graduated to 60 parts or 10 divisions to a mile.

The axle of the wheel runs in two hinges secured to the shafts; and so constructed that the wheel is easily detached from the body of the instrument.

Lieut.-Colonel Waugh's Pattern 10-Mile Perambulator.— This instrument is somewhat similar in construction to Lt.-Col. Everest's, but the shafts are longer and the wheel of greater circumference, being $150\frac{8}{10}$ inches. The diameter of the dial plates, is $5\frac{2}{10}$ inches; the upper one containing 42 teeth, the lower one 40. The upper dial is divided into 100 parts, the lower one into 20, the former being perforated to admit of the divisions on the lower plate being distinctly read.

The upper plate has a small wheel sunk into it, which is graduated to 10 divisions or miles, and propelled by a pinion wheel of 10 teeth secured in the centre of the lower plate, the upper part of this pinion wheel serving to secure the two plates together.

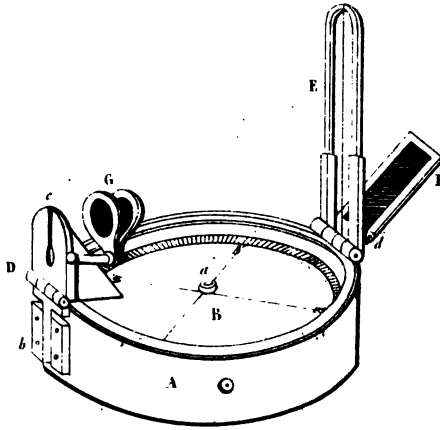
A very great improvement is made in the method of attaching the wheel and axle to the shafts; there are no hinges, the wheel and axle being secured by two screw bolts on each side, enabling the boxes of the axle to be clamped closer together, in the event of friction having worn them.

This instrument is better calculated for general work than any yet constructed, being very strong and at the same time conveniently portable.

CHAPTER II.

ON THE PRISMATIC COMPASS.

THE use of this little instrument is to measure horizontal angles only, or rather to take the Bearings of objects, when the angle can be deduced from the two Bearings, and from its portability is particularly adapted for filling in the detail of a map, where all the principal points have been correctly fixed by means of the Theodolite. In the figure, A represents the



compass-box, and B the card, which being attached to the magnetic needle, moves as it moves, round the agate centre, *a*, on which it is suspended. The circumference of the card is usually divided to 15' of a degree, but it is doubtful whether an angle can be measured by it even to that degree of accuracy:

c is a prism, which the observer looks through in observing with the instrument. The perpendicular thread of the sight-vane, *E*, and the divisions on the card appear *together* on looking through the prism, and the division with which the thread coincides, when the needle is at rest, is the magnetic azimuth of whatever object the thread may bisect. The prism is mounted with a hinge-joint, *D*, by which it can be turned over to the side of the compass-box, that being its position when put into the case. The sight-vane has a fine thread or horsehair stretched along its opening, in the direction of its length, which is brought to bisect any object, by turning the box round horizontally; the vane also turns upon a hinge-joint, and can be laid flat upon the box, for the convenience of carriage. *F* is a mirror, made to slide on or off the sight-vane, *E*; and it may be reversed at pleasure, that is, turned face downwards; it can also be inclined at any angle, by means of its joint, *d*; and it will remain stationary on any part of the vane, by the friction of its slides. Its use is to reflect the image of an object to the eye of the observer when the object is much above or below the horizontal plane. When the instrument is employed in observing the azimuth of the sun, a dark glass must be interposed; and the coloured glasses represented at *G*, are intended for that purpose; the joint upon which they act, allowing them to be turned down over the sloping side of the prism-box.

At *e*, is shown a spring, which being pressed by the finger at the time of observation, and then released, checks the vibrations of the card, and brings it more speedily to rest. A stop is likewise fixed at the other side of the box, by which the needle may be thrown off its centre; which should always be done when the instrument is not in use, as the constant playing of the needle would wear the point upon which it is balanced, and upon the fineness of the point, much of the accuracy of the instrument depends. A cover is adapted to the box, and the whole is packed in a leather case, which may be carried in the pocket without inconvenience.

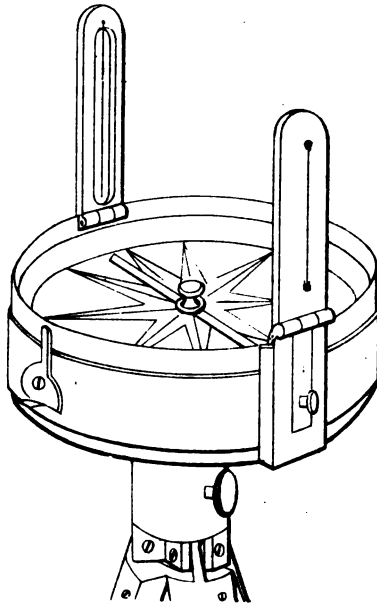
The method of using the instrument is very simple. First raise the prism in its socket *b*, until you obtain distinct vision of the divisions on the card, and standing at the place where the angles are to be taken, hold the instrument to the eye, and looking through the slit, *c*, turn round till the thread in the sight-vane bisects one of the objects whose azimuth, or angular distance from any other object is required; then, by touching the spring, *e*, bring the needle to rest, and the division on the card which coincides with the thread on the vane, will be the azimuth or Bearing of the object from the North or South points of the magnetic meridian. Then turn to any other object and repeat the operation; the difference between the Bearing of this object and that of the former, will be the angular distance of the objects in question. Suppose the former Bearing to be $40^{\circ} 30'$ and the latter $10^{\circ} 15'$, both East or both West, from the North or South, the angle will be $30^{\circ} 15'$.

The divisions in some are numbered from 0 to 180° South counting Eastward, and thence to 180° North counting Westward, others are numbered 5° , 10° , 15° , &c. round the circle to 360° , 90° representing East, 180° South, 270° West, and 360° North.

In using this instrument the Variation of the needle must always be attended to, for if the fixed points above alluded to have been surveyed on the *true* meridian of the earth, the Variation of the needle (which will be treated of hereafter) must be added or deducted to the observed Bearing to obtain the true meridional Bearing of the line.

OF THE SURVEYING COMPASS.

THE Surveying Compass consists of a compass-box, magnetic needle and two plain sights, perpendicular to the meridian line in the box, by which the Bearings of objects are taken from one station to another; it is used for the same purpose as the Prismatic Compass, for filling in the interior detail of a Survey by means of Bearings.

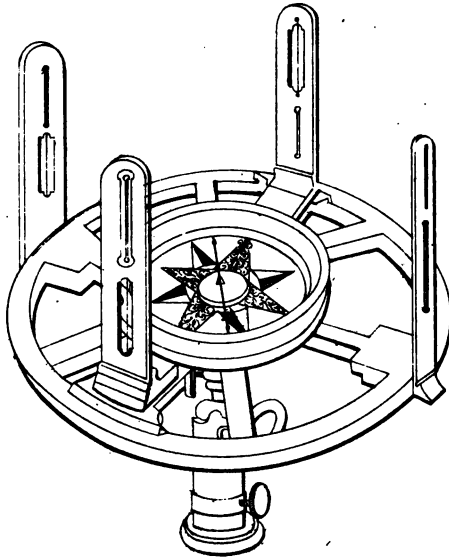


The sights are attached in various ways for portability, but are now generally made to turn down on a hinge, in order to lessen the bulk of the instrument and render it more convenient for carriage, the diameter of the box varies from $3\frac{1}{2}$ to 4 and 5 inches. Within the box is a graduated circle, the upper surface of which is divided into degrees only, and numbered 10° , 20° , 30° , &c., up to 360° . The bottom of the box is divided into four parts or Quadrants, each subdivided into 90° numbered from the North and South points each way, to the East and West points. The observer, therefore, has nothing to do, but to read off the actual number of degrees pointed out by the needle. This instrument is well adapted for first instruction to a Native.

OF THE CIRCUMFERENTOR.

THIS instrument is constructed on the same principle as the Surveying Compass, as to its needle and divided circle, but it possesses the advantages of a graduated limb and vernier

scale, whereby the unsteadiness of the needle and the difficulty of ascertaining with exactness the point at which it settles is obviated.



By the help of this index, Angles or Bearings may be taken with much greater accuracy than by the needle alone; and, as an angle may be ascertained by the index with or without the needle, it of course removes the difficulties, which would otherwise arise if the needle should at any time happen to be acted upon or drawn out of its ordinary position by extraneous matter; there is a clamping screw beneath, not visible in the figure, whereby the index may be fastened to the bottom of the box, and a screw, to fix the whole to the pin of the ball and socket, so that the body of the instrument and the index may be either turned round together, or the one turned round, and the other fixed, as occasion may require.

This instrument is frequently made with two extra sights on the graduated circle, at the points 360° and 180° , when it possesses the same properties as the common Theodolite and according as it is graduated, reads from 1 to 3 and 5 minutes.

ON THE PLANE TABLE.

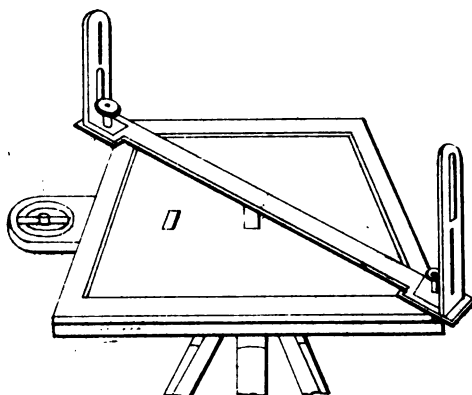
THE tabular part of this instrument is usually made of two well-seasoned boards, forming a parallelogram of about 15 inches long, and 12 inches broad; the size is occasionally varied to suit the intentions of the operator.

The aforesaid parallelogram is framed with a ledge on each side to support a box frame, which frame confines the paper on the table, and keeps it close thereto; the frame is therefore so contrived, that it may be taken off and put on at pleasure, either side upwards. Each side of the frame is graduated; one side is usually divided into scales of equal parts, for drawing lines parallel or perpendicular to the edges of the table, and also for more conveniently shifting the paper; the other face, or side of the frame, is divided into 360° , from a brass centre in the middle of the table, in order that angles may be measured as with a Theodolite; on the same face of the frame, and on two of the edges, are graduated 180° ; the centre of these degrees is exactly in the middle between the two ends, and about $\frac{1}{4}$ th part of the breadth from one of the sides.

A magnetic needle and compass box, covered with a glass, slides in a dovetail on the under side of the table, and is fixed there by a finger screw; it serves to point out the direction, and be a check upon the sights.

There is also a brass index somewhat longer than the diagonal of the table, at each end of which a sight is fixed; the vertical hair, and the middle of the edge of the index, are in the same plain; this edge is chamfered, and is usually called the fiducial edge of the index. Scales of different parts in an inch are usually laid down on one side of the index.

Under the table is a spring to fit on the pin of the ball and socket, by which it is placed upon a three-legged stand.



To place the paper on the table. Take a sheet of paper that will cover it, and wet it to make it expand, then spread it flat upon the table, pressing down the frame upon the edges to stretch it and keep it in a fixed situation; when the paper is dry it will, by contracting, become smooth and flat.

To shift the paper on the table. When the paper on the table is full, and there is occasion for more, draw a line in any manner through the farthest point of the last station line, to which the work can be conveniently laid down; then take off the sheet of paper, and fix another on the table; draw a line upon it in a part most convenient for the rest of the work; then fold, or cut the old sheet of paper by the line drawn on it; apply the edge to the line on the new sheet, and, as they lie in that position, continue the last station line upon the new paper, placing upon it the rest of the measures, beginning where the old sheet left off, and so on from sheet to sheet.

To fasten all the sheets of paper together, and thus form one rough plan, join the aforesaid lines accurately together, in the same manner as when the lines were transferred from the old sheets to the new one. But if the joining lines upon the old and new sheets have not the same inclination to the side of the table, the needle will not point to the original degree when the table is rectified. If the needle therefore should respect the same degree of the compass, the easiest way of drawing the line in the same position is to draw them both parallel to the same sides of the table, by means of the scales of equal parts on the two sides.

To use the table. Fix it at a convenient part of the ground, and make a point on the paper to represent that part of the ground.

Run a fine steel pin or needle through this point into the table, against which you must apply the fiducial edge of the index, moving it round till you perceive some remarkable object, or mark set up for that purpose. Then draw a line from the station point, along the fiducial edge of the index.

Now set the sights to another mark, or object, and draw that station line, and so proceed till you have obtained as many angular lines as are necessary from this station.

The next requisite, is the measure or distance from the station to as many objects as may be necessary by the chain, taking at the same time the offsets to the required corners or crooked parts of the hedges, setting off all the measures upon their respective lines upon the table.

Now remove the table to some other station, whose distance from the foregoing was previously measured; then lay down the objects which appear from thence, and continue these operations till your work is finished, measuring such lines as are necessary, and determining as many as you can by intersecting lines of direction, drawn from different stations.

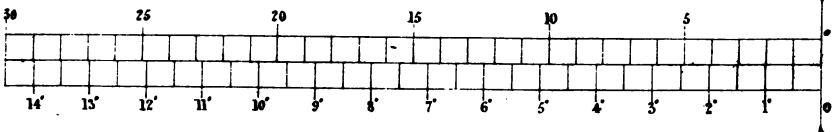
CHAPTER III.

OF THE VERNIER.

THE Vernier scale which is applied to instruments, both for measuring angles and distances when great accuracy is required, will now be noticed.

We will suppose that the horizontal circle of a Theodolite is divided into 360 degrees, and that each division or degree is subdivided into half degrees, or 30 minutes: without such a contrivance as the Vernier, we can only guess at the number of minutes, when the index does not exactly agree with one of the subdivisions; but by means of a Vernier, we are enabled to read off an angle on the circle of an ordinary Theodolite to a single minute; and may, if the horizontal circle be very large, read off to a few seconds with the greatest certainty.

VERNIER SCALE—to one minute of a degree.



$14\frac{1}{2}$ degrees, or 29 half-degrees.

The construction of this ingenious contrivance is simple. Suppose we want to read off to one minute—Take the length of 29 half-degrees on the horizontal circle, and divide that distance into 30 equal parts; this forms the Vernier, which is marked for convenience, 5, 10, 15, 20, 25, 30, from one end, or the zero. Set the Vernier, which is so constructed as to slide evenly along the graduated limb of the instrument, to the horizontal circle, so that zero of the former may be in contact with zero of the circle; then the last division, marked 30, of the Vernier will, of course, agree with $14\frac{1}{2}^{\circ}$, or 29 half-degrees of the circle, and the proportion of each division of the Vernier, will be to a division of the circle, as 29 to 30. If the zero of the Vernier be moved from the zero of the circle, then the first coincidence that takes place between a division of the Vernier with one on the circle, indicates the number of minutes passed over. To read off an angle on the horizontal circle, use a magnifying glass, and notice how many degrees have been passed over by the zero of the Vernier: For example: Let us suppose that the arrow at zero of the Vernier has passed the 21st degree of the circle: then, for the number of minutes in addition, look along the Vernier, until one of its divisions is found to agree exactly with a division on the circle below it: we will suppose, that the 14th division of the Vernier does so: then the angle is $21^{\circ} 14'$.

OF THE THEODOLITE.

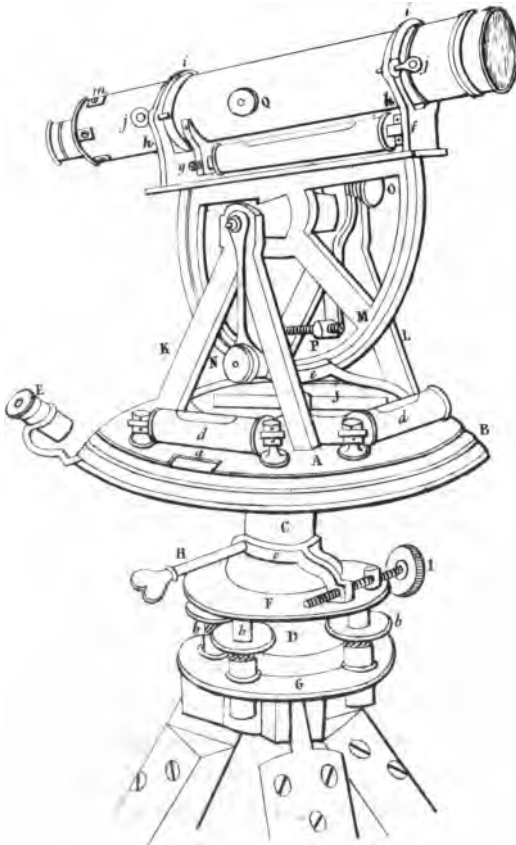
As an angular instrument the Theodolite has from time to time received such improvements, that it may now be considered the most important one employed in Surveying. They are of various modes of construction, but we shall here confine ourselves to the two patterns in general use on the Indian Surveys.

Description of the Theodolite. This instrument (as represented in the next page) consists of two circular plates, A and B, called the horizontal limb, the upper, or vernier plate, A, turning freely upon the lower, both having a horizontal motion by means of the vertical axis, C. This axis consists of two parts, external and internal, the former secured to the graduated limb, B, and the latter to the vernier plate, A. Their form is conical, nicely fitted and ground into each other, having an easy and a very steady motion; the external centre also fits into a ball at D, and the parts are held together by a screw at the lower end of the internal axis.

The diameter of the lower plate is greater than that of the upper one, and its edge is chamfered off and covered with silver, to receive the graduations: on opposite parts of the edge of the upper plate, or 180° apart, a short space, *a*, is also chamfered, forming with the edge of the lower plate a continued inclined plane: these spaces are likewise covered with silver, and form the Verniers. The lower limb is usually graduated to 30 minutes of a degree, and it is subdivided by the Vernier to single minutes, which being read off by the magnifying glass, E, half or even quarter minutes can easily be estimated.

The parallel plates, F and G, are held together by a ball and socket at D, and are set firm and parallel to each other by four milled-headed screws, three of which, *b, b, b*, are shown in the figure; these turn in sockets fixed to the lower plate, while their heads press against the under side of the upper plate, and being set in pairs, opposite each other, they act in contrary directions; the instrument by this means is set up level for observation.

Beneath the parallel plates is a female screw adapted to the staff head, which is connected by brass joints to three mahogany legs, so constructed that when shut up they form one round staff, secured in that form for carriage, by rings put on



them ; and when opened out they make a very firm stand, be the ground ever so uneven.

The lower horizontal limb can be fixed in any position, by tightening the clamping screw, H, which causes the collar, c,

R

to embrace the axis, C, and prevent its moving; but it being requisite that it should be fixed in some precise position more exactly than can be done by the hand alone, the whole instrument, when thus clamped, can be moved any small quantity by means of the tangent screw, I, which is attached to the upper parallel plate. In like manner the upper or vernier plate can be fixed to the lower, in any position, by a clamp which is also furnished with a tangent-screw. The motion of this limb, and of the vertical arc, hereafter to be described, is sometimes effected by a rack and pinion; but this is greatly inferior, where delicacy is required, to the slow motion produced by the clamp and tangent-screw.

Upon the plane of the vernier plate, two spirit-levels, *d d*, are placed at right angles to each other, with their proper adjusting screws: their use is to determine when the horizontal limb is set level: a compass also is placed at J.

The frames K and L support the pivots of the horizontal axis of the vertical arc (or semicircle) M, on which the telescope is placed. The arm which bears the microscope, N, for reading the altitudes or depressions, measured by the semicircle, and denoted by the vernier, *e*, has a motion of several degrees between the bars of the frame, K, and can be moved before the face of the vernier for reading it off. Another arm clamps the opposite end of the horizontal axis by turning the screw, O, and has a tangent-screw at P, by which the vertical arc and telescope are moved very small quantities up or down, to perfect the contact when an observation is made.

One side of the vertical arc is inlaid with silver, and divided to single minutes by the help of its vernier; and the other side shows the difference between the hypotenuse and base of a right-angled triangle, or, the number of links to be deducted from each chain's length, in measuring up or down an inclined plane, to reduce it to the horizontal measure. The level, which is shown under and parallel to the telescope, is attached to it at one end by a joint, and at the other by a

capstan-headed screw, *f*, which being raised or lowered, will set the level parallel to the optical axis of the telescope, or line of collimation; the screw, *g*, at the opposite end, is to adjust it laterally, for true parallelism in this respect. The telescope has two collars, or rings, of bell metal, ground truly cylindrical, on which it rests in its supports, *h, h*, called *Y's*, from their resemblance to that letter; and it is confined in its place by the clips, *i, i*, which may be opened by removing the pins *j, j*, for the purpose of reversing the telescope or allowing it a circular motion round its axis during the adjustment.

In the focus of the eye-glass are placed three lines, formed of spider's web, one horizontal, and two crossing it, so as to include a small angle between them; a method of fixing the wires which is better than having one perpendicular wire, because an object at a distance can be made to bisect the said small angle with more certainty than it can be bisected by a vertical wire. The screws adjusting the cross wires are shown at *m*: there are four of these screws, two of which are placed opposite each other, and at right angles to the other two, so that by easing one and tightening the opposite one of each pair, the intersection of the cross wires may be placed in adjustment.

The object-glass is thrust outwards by turning the milled head, *Q*, on the side of the telescope, that being the means of adjusting it to show an object distinctly.

A brass plummet and line are packed in the box with the Theodolite, to suspend from a hook under its centre, by which it can be placed exactly over the station from whence the observations are to be taken; likewise, if required, two extra eye-pieces for the telescope, to be used for astronomical observations: the one inverts the object, and has a greater magnifying power, but having fewer glasses possesses more light; the other is a diagonal eye-piece, which will be found extremely convenient when observing an object that has a considerable altitude; the observer avoiding the unpleasant and painful

position he must assume in order to look through the telescope when either of the other eye-pieces is applied. A small cap containing a dark-coloured glass is made to apply to the eye-end of the telescope, to screen the eye of the observer from the intensity of the sun's rays, when that is the object under observation. A magnifying glass mounted in a horn frame, a screw-driver, and a pin to turn the capstan-screws for the adjustments, are also furnished with the instrument.

THE ADJUSTMENTS.

THE first adjustment is that of the line of collimation; that is, to make the intersection of the cross wires coincide with the axis of the cylindrical rings on which the telescope turns: it is known to be correct, when an eye, looking through the telescope, observes their intersection continue on the same point of a distant object during an entire revolution of the telescope. The usual method of making this adjustment is as follows:

First, make the centre of the horizontal wire coincide with some well defined part of a distant object; then turn the telescope half round in its Y's till the level lies above it, and observe if the same point is again cut by the centre of the wire; if not, move the wire one-half the quantity of deviation, by turning two of the screws at *m*, (releasing one, before tightening the other,) and correct the other half by elevating or depressing the telescope; now if the coincidence of the wire and object remains perfect in both positions of the telescope, the line of collimation in altitude or depression is correct, but if not, the operation must be repeated carefully, until the adjustment is satisfactory. A similar proceeding will also put the vertical line correct, or rather, the point of intersection, when there are two oblique lines instead of a vertical one.

The second adjustment is that which puts the level attached to the telescope parallel to the rectified line of collimation. The clips, *i*, *i*, being open, and the vertical arc clamped, bring the air-bubble of the level to the centre of its glass tube, by

turning the tangent-screw, P; which done, reverse the telescope in its Y's, that is, turn it end for end, which must be done carefully, that it may not disturb the vertical arc, and if the bubble resume its former situation in the middle of the tube, all is right; but if it retires to one end, bring it back one-half, by the screw, *f*, which elevates or depresses that end of the level, and the other half by the tangent-screw, P: this process must be repeated until the adjustment is perfect; but to make it completely so, the level should be adjusted laterally, that it may remain in the middle of the tube when inclined a little on either side from its usual position immediately under the telescope, which is effected by giving the level such an inclination, and if necessary turning the two lateral screws at *g*; if making the latter adjustment should derange the former, the whole operation must be carefully repeated.

The third adjustment is that which makes the azimuthal axis, or axis of the horizontal limb, truly vertical.

Set the instrument as nearly level as can be done by the eye, fasten the centre of the lower horizontal limb by the staff-head clamp, H, leaving the upper limb at liberty, but move it till the telescope is over two of the parallel plate-screws; then bring the bubble of the level under the telescope, to the middle of the tube, by the screw, P; now turn the upper limb half round, that is 180° , from its former position; then, if the bubble return to the middle, the limb is horizontal in that direction; but if otherwise, half the difference must be corrected by the parallel plate-screws over which the telescope lies, and half, by elevating or depressing the telescope, by turning the tangent-screw of the vertical arc; having done which, it only remains to turn the upper limb forward or backward 90° , that the telescope may lie over the other two parallel plate-screws, and by their motion set it horizontal. Having now levelled the limb-plates by means of the telescope level, which is the most sensible upon the instrument, the other air-bubbles fixed upon the vernier plate, may be brought to the

middle of their tubes, by merely giving motion to the screws which fasten them in their places.

The vernier of the vertical arc may now be attended to; it is correct, if it points to zero when all the foregoing adjustments are perfect; and any deviation in it is easily rectified, by releasing the screws by which it is held, and tightening them again after having made the adjustment: or, what is perhaps better, note the quantity of deviation as an index error, and apply it, plus or minus, to each vertical angle observed. This deviation is best determined by repeating the observation of an altitude of depression in the reversed positions, both of the telescope and the vernier plate; the two readings will have equal and opposite errors, one-half of their difference being the index error. Such a method of observing angles is decidedly the best, since the mean of any equal number of observations taken with the telescope reversed in its Y's, must be free from the effects of any error that may exist in the adjustment of the vernier, or zero of altitude.

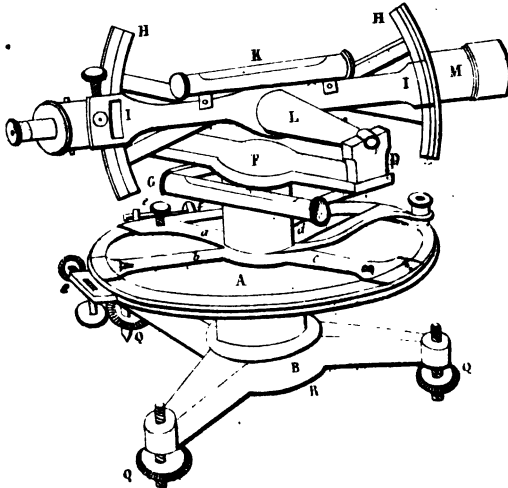
The Theodolite, as constructed in the manner we have described, is not inconveniently heavy, as the diameter of the horizontal limb seldom exceeds five inches; but when the diameter is increased, the other parts must be made proportionably large and strong, and the instrument becomes too weighty and cumbersome to be easily carried from station to station. The object of increasing the dimensions, is to enable the instrument to furnish more accurate results, by applying a telescope of greater power, and by a more minute subdivision of the graduated arcs. With the increase of size, a small variation takes place in the construction, principally consisting in the addition of a second telescope, and in the manner of attaching the supports, K and L, to the horizontal limb, to afford the means of adjusting the horizontal axis, and of course, making the telescope and vertical arc move in a vertical plane. In the smaller instruments this is done by construction, but in the larger ones, the supports, K

and L, are attached to a stout frame, which also carries the compass box, instead of being fixed, as represented in our figure, to the upper horizontal plate. The frame is attached to the limb by three capstan-headed screws, forming an equilateral triangle, two of them lying parallel to the horizontal axis, and the third in the direction of the telescope; the adjustment is made by means of these screws. To prove its accuracy, set up the Theodolite in such a situation that some conspicuous point of an elevated building may be seen through the telescope, both directly and by reflection, from a basin of water, or, what is better, of oil or quicksilver. Let the instrument be very correctly levelled, and if, when a vertical motion is given to the telescope, the cross wires do not cut the object seen, both directly and by reflection, it is a proof that the axis is not horizontal; and its correction is effected by giving motion to the screws above spoken of, which are at right angles to the telescope, or in the direction of the horizontal axis; or a long plumb-line may be suspended, and if the cross wires of the telescope, when it is elevated and depressed, pass exactly along the line, it will be a proof of the horizontality of the axis. The third screw, or that which is under the telescope, serves for adjusting the zero of altitude, or vernier of the vertical arc.

A second telescope is sometimes attached to the instrument beneath the horizontal limb; it admits of being moved, both in a vertical and horizontal plane, and has a tangent-screw attached for slow motion: its use is to detect any accidental derangement that may occur to the instrument whilst observing, which may be done by it in the following manner. After levelling the instrument, bisect some very remote object with the cross wires of this second telescope, and clamp it firm; if the instrument is steady, the bisection will remain permanent whilst any number of angles are measured, and by examining the bisection from time to time, during the operation at the place where the instrument is set up, any error arising from this cause may be detected and rectified.

Having given a description of the common Theodolite, we now proceed to notice a very superior instrument, designed by Lieutenant Colonel Everest, Bengal Artillery, the late Surveyor General of India, and manufactured by the celebrated makers, Troughton and Simms, generally known by the distinction of "Everest's Pattern" and which is universally sought after by Surveyors of the present day. The description of this instrument is given in "Simms' Treatise on Mathematical Instruments," which book ought to be in the hands of every Surveyor, but knowing from experience the difficulty of obtaining works of reference, in the more distant parts of India, we have not hesitated in this, as well as in other instances, to borrow liberally from the work. These instruments are of the most perfect construction and so admirably adapted for the purposes of the Revenue Survey, that too much praise cannot be bestowed on the makers. In principle they are similar to Theodolites of much larger dimensions, and consequently their essential adjustments are made in the same manner.

The following figure represents an instrument of this kind:

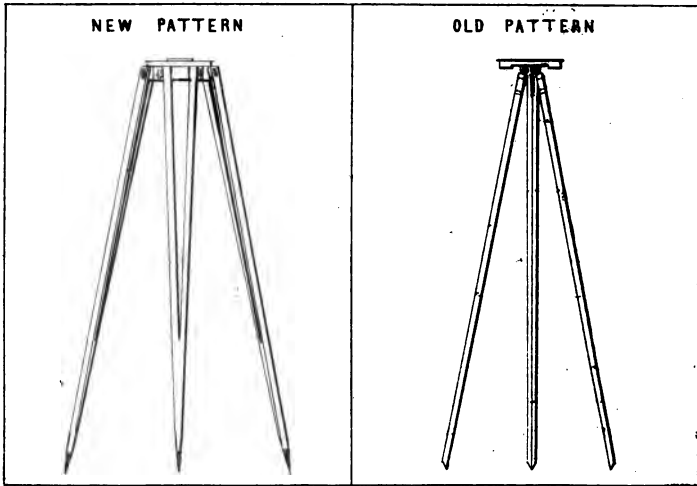


The horizontal circle, or limb, A of this instrument consists of one plate only, which, as usual, is graduated at its circumference. The index is formed with four radiating bars, *a, b, c, d*, having verniers at the extremities of three of them marked A, B and C, for reading the horizontal angles, and the fourth carries a clamp, *e*, to fasten the index to the edge of the horizontal limb, and a tangent-screw, *f*, for slow motion. These are connected with the upper works which carry the telescope, and turning upon the same centre, show any angle through which the telescope has been moved. The instrument has also the power of repeating the measurement of an angle; for the horizontal limb being firmly fixed to a centre, movable within the tripod support, R, and governed by a clamp and tangent-screw, *s*, can be moved with the same delicacy, and secured with as much firmness, as the index above it.

The tripod support, which forms the stand of the instrument, has a foot-screw at each extremity of the arms which form the tripod; the heads of the foot-screws are turned downwards, and have a flange (or shoulder) upon them, so that when they rest upon a triangular plate fixed upon the staff-head, another plate locks over the flange, and being acted upon by a spring, retains the whole instrument firmly upon the top of the staff. The advantage of the tripod stand is, that it can easily be disengaged from the top of the staff, and placed upon a parapet or other support, in situations where the staff cannot be used.

There is another kind of stand much preferable to the one usually furnished with Instruments and now in general use on the Revenue Surveys; it consists of a wooden triangular frame, on which is fixed the brass tripod of the Theodolite; the legs are attached to this frame by means of a brass bolt passing through the frame and head of the legs, with a screw and nut at each end, which serves to tighten or loosen the legs at pleasure, the other end of the legs being furnished with an iron spike. The stands are not perhaps

so portable as those folding up into one piece, but they are generally more serviceable, and can be made much steadier for observations.



The telescope is mounted in the following manner—The horizontal axis, L, and the telescope, M, form one piece, the axis crossing the telescope about its middle, and terminating at each extremity in a cylindrical pivot. The pivots rest upon low supports, (only one of them, D, being visible in the figure,) carried out from the centre, on each side, by a flat horizontal bar, F, to which a spirit-level, G, is attached for adjusting the axis to the horizontal plane. The vertical angles are read off on two arcs of circles, H, H, which have the horizontal axis at their centre, and being attached to the telescope, move with it in a vertical plane. An index, upon the same centre, carries two verniers, I, I, and it has a spirit-level, K, attached to it, by which the index can be set in a horizontal position, so that whatever position the teles-

cope, and consequently the graduated arcs, may have, when an observation is made, the mean of the two readings will denote the elevation or depression of the object observed, from the horizontal plane. On the upper part of the telescope is fixed a narrow box, containing a magnetic needle, for observing the Bearings of objects.

The following are the adjustments of this instrument: First: to set the instrument level: to accomplish this, bring the spirit-bubble, G, attached to the horizontal bar in a direction parallel to two of the foot-screws, and by their motion cause the air-bubble to assume a central position in the glass tube; then turn the telescope, level, &c. half round, and if the bubble is not central, correct half the deviation by raising or lowering one end of the level itself, and the other half by the foot-screws, which in this instrument perform an office similar to that of the parallel plate-screws of the Theodolite already described.

Having perfected this part, turn the telescope a quarter round, and the level will be over the third foot-screw, which must be moved to set the level correct, and this part of the adjustment will be complete.

The line of collimation must be next attended to: direct the telescope to some well-defined object, and make the vertical wire bisect it; then turn the axis end for end, an operation which of course inverts the telescope, and if the object be not now bisected by the vertical wire, correct half the deviation by the collimating screws at the eye-end of the telescope, and the other half by giving motion in azimuth to the instrument, and this must be repeated till the adjustment is satisfactorily accomplished.

Finally, for the zero of altitude. Take the altitude or depression of an object with the vertical sector in reversed positions; half the sum will be its true altitude, or depression, and to this, let the verniers be set. Again carefully direct the telescope to the object, making the bisection by the screws which retain the

index in a horizontal position, and finally correct the level by the adjusting screws at one of its ends.

THE METHOD OF OBSERVING WITH THE THEODOLITE.

To level the instrument.—The instrument being placed exactly over the station from whence the angles are to be taken, by means of the plumb-line suspended from its centre, it must be set level by the foot-screws *Q, Q, Q*. Thus: place the level *G*, in a direction parallel to two of the foot-screws, when the end of the level *K*, will fall over the third foot-screw; by the motion of the foot-screws under the level *G*, turn them both inwards or both outwards, according as you want the bubble to go to the right or left, until it becomes stationary in the middle: then proceed to the third foot-screw, and turn it to the right or left, until the bubble in the level *K*, also becomes stationary in the middle. In performing this last operation, the level *G*, will be perhaps thrown out, which must be again levelled, and another examination made of the level *K*. When both bubbles remain stationary in the middle, the instrument is ready for observation.

To observe an angle.—By means of the clamp, *e*, and tangent-screw, *f*, set the vernier marked *A* to 360° ; then turn the limb round, and with the lower clamp and tangent-screw, *s*, fix the cross-wires in the telescope on any object. Then loosen the upper clamp, *e*, and turn the upper limb round, fixing the cross-wires by the same clamp and tangent-screw on any other object; the angle subtended can be then read off on the instrument.

Another method.—Clamp the lower horizontal limb firmly in any position, and direct the telescope to one of the objects to be observed, moving it till the cross-wires and object coincide; then clamp the upper limb, and by its tangent-screw make the intersection of the wires nicely bisect the object; now read off the two verniers, the degrees, minutes, and seconds of (either)

one, which call A, and the minutes and seconds only of the other, which call B, and take the mean of the readings thus:—

$$\begin{array}{r}
 A = 142^{\circ} \quad 36' \quad 30'' \\
 B = \quad \text{,,} \quad 37 \quad 0 \\
 \hline
 \text{Mean} = 142 \quad 36 \quad 45 \\
 \hline
 \end{array}$$

Next release the upper plate, and move it round until the telescope is directed to the second object (whose angular distance from the first is required,) and clamping it, make the cross-wires bisect this object, as was done by the first; again read off the two verniers, and the difference between their mean, and the mean of the first reading, will be the angle required.

To repeat an angle.—Leave the upper plate clamped to the lower, and release the clamp of the latter; now move the whole instrument (bodily) round towards the first object, till the cross-wires are in contact with it; then clamp the lower plate firm, and make the bisection with the lower tangent-screw. Leaving it thus, release the upper plate, and turn the telescope towards the second object, and again bisect it by the clamp and slow motion of the upper plate. This will complete one repetition, and if read off, the difference between this and the first reading will be double the real angle. It is, however, best to repeat an angle four or five times; then the difference between the first and last readings (which are all that it is necessary to note) divided by the number of repetitions will be the angle required.

The magnetic Bearing of an object is taken, by simply reading the angle pointed out by the compass-needle, when the object is bisected; but it may be obtained a little more accurately by moving the upper plate (the lower one being clamped) till the needle reads zero, at the same time reading off the horizontal limb; then turning the upper plate about, bisect the object and read again; the difference between this reading and the former will be the bearing required.

In taking angles of elevation or depression, it is scarcely necessary to add, that the object must be bisected by the horizontal wire, or rather by the intersection of the wires and that after observing the angle with the telescope in its natural position, it should be repeated with the telescope turned half round in its Y's, that is, with the level uppermost; the mean of the two measures will neutralize the effect of any error that may exist in the line of collimation.

The altitude and azimuth of a celestial object may likewise be observed with the Theodolite, the former being merely the elevation of the object taken upon the vertical arc, and the latter, its horizontal angular distance from the meridian.

We here suggest a few hints on the use of these delicate instruments.

1st. They must not be handled roughly. In taking them in and out of the box, it should be done with the greatest care, not knocking them against the sides of the box or forcing them into their positions within it; the boxes are so constructed, that the instrument fits exactly into its own place, and unless it settles down of itself, forcing it will throw the instrument out of adjustment.

2nd. Never permit a Native Surveyor to apply oil to any part of the instrument, under the idea that it will work easier; a new instrument will perhaps work stiff at first, but a very few days' use will rectify it, the application of oil is nothing but a resting place for dust that is always flying about in the field; this dust works up into the various screws, wears them, and at the end of six months the instrument requires repair, or is next to useless; if oil is necessary, it should be applied by the Assistant, and then wiped off as dry as possible.

3rd. Always throw the needle off its centre by the stop fixed on one side of the box, when the instrument is not in use, as the constant playing of the needle wears the pivot upon which it is balanced, and on the fineness of this point depends the ac-

curacy of the Bearing. This is equally applicable to the Prismatic Compass and Circumferentor.

4th. Always wipe the dust off the instrument on commencing and finishing a day's work, with a camel hair brush, as this will tend to prevent any accumulation of dirt about it: a Surveyor should partly be judged of by the state of his instrument.

5th. When once the variation of the needle is ascertained, never remove the box from off the telescope, for unless it is screwed on again, in the exact position it originally was, the variation of the needle will alter.

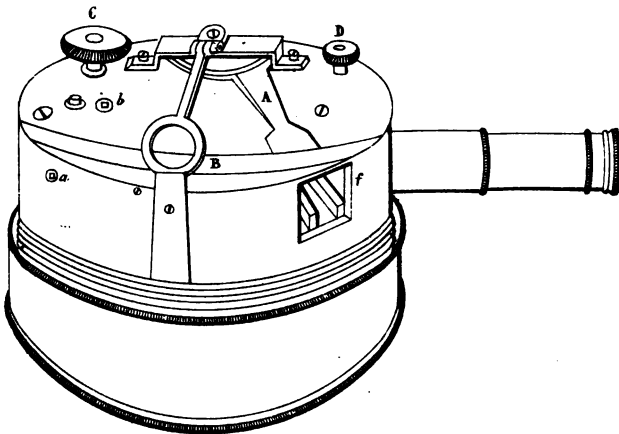
6th. On the care a Surveyor takes of his Theodolite, depends much of the accuracy of his work; if he neglects and is careless about the former, he will one day have to lament over the accumulated errors of the latter.

7th. Native agency being employed to a very great extent in the Revenue Surveys, the strictest surveillance is necessary on the part of Assistants to guard against the great negligence in this respect generally prevalent amongst Native Surveyors. It is the duty also of the Revenue Surveyor to examine and personally satisfy himself, that his instruments are in efficient working order.

CHAPTER IV.

THE BOX OR POCKET SEXTANT.

THE Pocket Sextant combines numerous valuable properties: it measures an angle to one minute of a degree, requires no support but the hand, may be used on horseback, maintains its adjustment long, and is easily re-adjusted when put out of order. It will determine the latitude by a meridian altitude to one minute; and an approximation may even be made with it to the longitude, by means of lunar observations. Further, it is very portable, forming when shut up, a circular box under 3 inches in diameter, and only $1\frac{1}{2}$ inches deep.



The figure in the adjoining page represents the instrument screwed to its box, for convenience of holding in the hand and with the telescope drawn out. A is the index arm, having a vernier adjusted to the graduated arc B, which latter is numbered to 140° , but the sextant will not measure an angle greater than about 125° . The index is moved by the milled-head C, acting upon a rack and pinion in the interior. Two mirrors are placed inside; the large one, or index mirror, is fixed to, and moves with, the index: the other, called the horizon glass, is only half-silvered. The proper adjustment of the instrument depends on these glasses being parallel, when the index is at zero—while they are, at the same time, perpendicular to what is termed the plane of the instrument, represented by its upper surface or face. To observe whether the instrument is in perfect adjustment, remove the telescope by pulling it out, and supply its place with a slide for the purpose, in which is a small hole to look through: then place the index accurately at zero, and direct the instrument, holding it horizontally, towards the sharp angle of a building, not less than half a mile distant, applying the eye so as to see both through the hole in the slide, and also through the unsilvered part of the horizon glass: the same object ought then to be so reflected, from the index mirror to the silvered part of the horizon glass, as to seem but one with the object seen direct: if such is not the case, a correction becomes necessary, which is thus performed: D is a key, removable at pleasure, that fits two keyholes, the one at *a*, the other at *b*. Apply this key at *a*, and gently turn, until the reflected object, and the one seen direct, seem but as one. The glasses are then parallel.

The next point is to examine whether the horizon glass is perpendicular to the plane of the instrument. For this purpose, hold the sextant horizontally, and look at the distant horizon; then, if any adjustment is wanted, two horizons will appear, or the reflected one will be higher or lower than the one seen direct; should this be the case, apply the key at *b*, so

as to bring the two horizons together. It must be observed that the large or index mirror being correct by construction, it can want no alteration.

By looking at the sun, we can always satisfy ourselves with respect to the adjustments; the telescope has a dark glass at the eye end, and with this on, we have only to place the index at zero, and using the telescope, to look at the sun—when, provided the instrument is in exact adjustment, one perfect orb only will be seen. If the reflected image projects beyond the other, then correction is necessary. The full moon will answer as well as the sun for this purpose; but the dark glass at the eye end of the telescope must then be removed. The instrument is provided with two other dark glasses, which sink out of the way by raising two little levers at *f*.

It has been mentioned above, that for trying the adjustments of the sextant, an object must be half a mile off; this is on account of what is called the parallax of the instrument, occasioned by the necessity of placing the eye of the observer on one side of the index mirror. Could we look from the middle of it, there would be no parallax; which is the angle subtended by the point of vision, and centre of the index glass, when observing any near object: consequently, as the distance of an object is increased, this angle diminishes, and at length, becomes as nothing when compared with it. Half a mile is considered sufficient for all error to vanish, but at half that distance, it is scarcely perceptible.

To take an angle, the observer looks either through the telescope, or hole in the slide (having previously raised the levers of the dark glasses at *f*), at the *left* hand object, holding the sextant horizontally in his left hand; with his right, he turns the milled-head C, until the other object, reflected from the index glass, appears upon the silvered part of the horizon glass, exactly covering or agreeing with the left hand object, seen direct through the unsilvered portion of the horizon glass: the angle is then obtained by the vernier to one minute.

If the required angle be a vertical one, the sextant is held in a vertical position, by the right hand, while the left turns the milled-head C, until the object is brought down to the horizon.

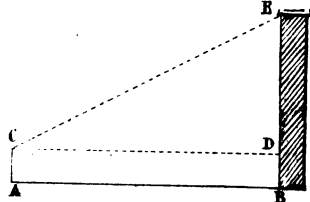
When the altitude of a celestial body is taken at sea, it is brought down, as the term is, to the natural horizon, and the measure of the angle, or height of the object, is read off upon the graduated arc: but on land, the natural horizon can seldom be used, on account of its irregularity; recourse is then had to, what is called, an artificial horizon, (page 151) such as a vessel containing water, mercury or other fluid. The observer then places himself in a situation, to see the reflected image of the sun, or other body, in the fluid: he has only then to bring down the image, as reflected from the index glass, until it reaches its reflection in the fluid: the altitude will then be *half* the number of degrees, indicated by the graduated arc, subject to certain corrections, not necessary to be explained here.

The height and distance of objects, as walls or buildings, whether accessible or otherwise, may be obtained in a very simple and expeditious manner with the sextant, by means of the little table below:—

Multiplier.	Angle.	Angle.	Divisor.
1	..... 45° 00'	..... 45° 00'	1
2	..... 63 26	..... 26 34	2
3	..... 71 34	..... 18 26	3
4	..... 75 58	..... 14 02	4
5	..... 78 41	..... 11 19	5
6	..... 80 32	..... 9 28	6
8	..... 82 52	..... 7 08	8
10	..... 84 17	..... 5 43	10

Make a mark upon the object, if accessible, equal to the height of your eye from the ground. Set the index to one of the angles in the table, and retire on *level* ground, until the top is brought by the glasses to coincide with the mark; then, if the angle be greater than 45°, multiply the distance by the

corresponding figure to the angle in the table; if it be less, divide—and the product, or quotient, will be the height of the object above the mark. Thus, let EB be a wall, whose height we want to know; and $26^{\circ} 34'$ the angle selected. Make a mark at D equal to the height of the eye; then step back from the wall, until the top at E is brought down by the glasses to coincide with the mark: measure the distance AB, namely, from your station to the wall, and divide that distance by 2, the figure corresponding to $26^{\circ} 34'$, this will give the height DE, to which BD must be added.

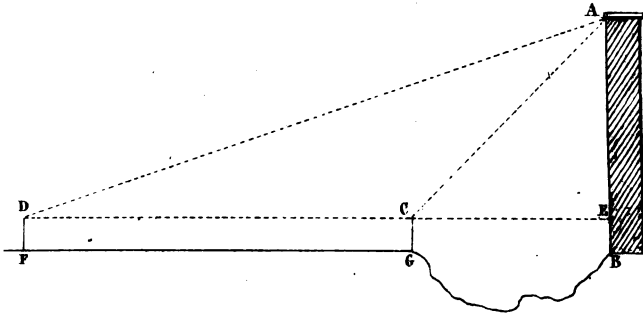


The *parallax* of the instrument exerts an influence on measurements of this kind, from the object being near. To correct it, we have only to ascertain its amount, by placing the index at zero, and looking through the instrument at the top of the wall; when, if influenced by parallax, it will appear as a broken line; but by moving the index a little way on the *arc of excess*, or to the left of zero, the broken line will reunite, and the adjustment be effected. When any quantity is taken thus on the arc of excess, the amount must be deducted, when setting the instrument to any of the tabular angles.

When the object is inaccessible—set the index to the greatest of the divisor angles in the table, that the least distance from the object will admit of, and advance or recede, till the top of it is brought down by the sextant to a level with the eye: at this place, set up a staff, equal to the height of the eye. Then set the index to one of the lesser angles, and retire in a line from the object, till the top is brought to coincide with the staff, set up to indicate the height of the eye; place a mark here, and measure the distance between the two marks; this, divided by the difference of the figures opposite the angles used, will give the height of the object above the height of the eye or mark. *For the distance*, multiply the height of the

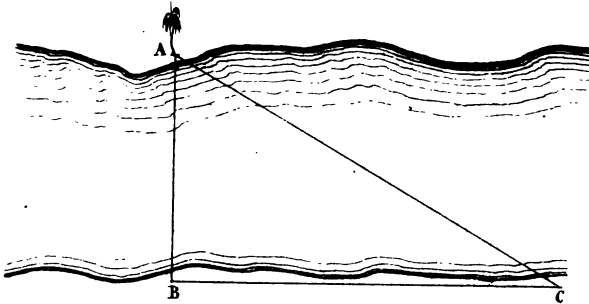
object by the numbers against either of the angles made use of, and the product will be the distance of the object from the place where such angle was used.

The above will be understood better by means of a diagram. Let AB be a wall, not to be approached nearer than C ; and that we find, upon trial, that this distance admits of our using the angle 45° ; assume a point E on the wall, as the height of the eye; then the index being set to 45° , fix yourself so that the glasses shall bring the top A to coincide with E . At this point, place a staff, CG , equal to the height of the eye. Now select any one of the lesser angles from the tables— 18° $26'$



for instance, and retire until the point A agrees with the top of the staff CG , which occurs at F . Place a mark at F , and measure the distance from F to G ; which, divided by 2, the difference of the numbers opposite to the angles used, will give AE —to which add $BE = CG$, the height of the eye, and the total height AB is obtained. Then, for the distance—the height AE , multiplied by 3, its corresponding figure, will give the length DE : and AE multiplied by 1, will, in like manner, give $GB = AE$ in this instance.

Horizontal distances, as well as heights, may be ascertained by means of the table, where the ground is level. Thus suppose, we wish to measure the breadth of a river, denoted by the line AB : set the index to an angle of the table; place a mark at B , and proceed in a direction C , at right angles to AB , until the glasses of the instrument shew A and B in contact: then



will the distance AB be a product or quotient of the base BC, according to the angle used. For instance, if the angle $26^{\circ} 34'$ be used, then must the distance BC be divided by 2.

The method of determining heights and distances by the small table, is valuable, as the operations are speedily performed, and with tolerable accuracy; while it enables us to dispense with logarithmic tables and trigonometry.

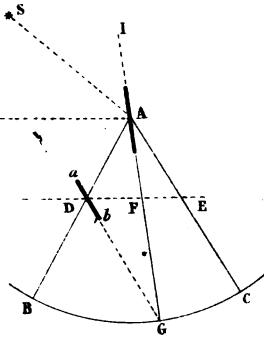
The pocket sextant is very useful when taking offsets: set the index to 90° , and walk along the station line; then, when you wish to ascertain at what point any mark or object becomes perpendicular to the station line, you have only to look through the sextant at the left hand object, and move forward or backward until the two objects, namely, the offset mark, and that on your station line, are brought to coincide. Or, if you wish to lay off a line at right angles to another, send your assistant with a staff in the required direction, and having set the index at 90° , cause him to move right or left until his staff and your other mark are made to agree.

ON THE SEXTANT.

THE sextant is an instrument for determining the angles of elevation of objects, or the altitudes of celestial bodies. To a Surveyor who generally has only Theodolites of small dimensions, it is most useful for determining his latitude or longitude.

The principle of its construction may be gathered from the following demonstration:

Let ABC represent a Sextant, having an index, AG, (to which is attached a mirror at A) movable about A as a centre, and denoting the angle it has moved through, on the arc, BC; also let the half-silvered (or horizon) glass, *a b*, be fixed parallel to AC; now a ray of light, SA, from a celestial object, S, impinging against the mirror, A, is reflected off at an equal angle, and striking the half-silvered glass at D, is again reflected to E, where the eye likewise receives through the transparent part of that glass a direct ray from the horizon. Then the altitude, SAH, is equal to double the angle, CAG, measured upon the limb, BC, of the instrument.

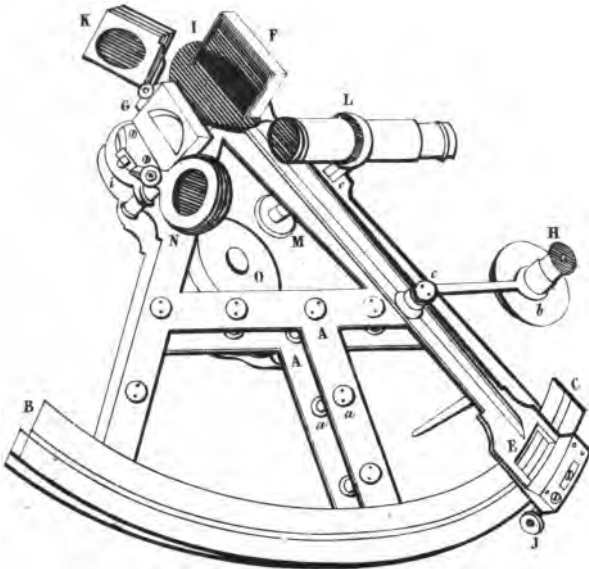


For the reflected angle, BAG (or DAF) = the incident angle, SAI, and the reflected angle, *b*DE = the incident *a*DA = DAE = DEA, because *a b* is parallel to AC. Now, HAI = DFA = (FAE + FEA), and DAE, being equal to DEA, it follows that HAI = (DAE + FAE). From HAI and (DAE + FAE) take the equal angles, SAI and DAF, and there remains SAH = 2 FAE, or 2 GAC; or, in other words, the angle of elevation, SAH, is equal to double the angle of inclination of the two mirrors, DGA, being equal to GAC.

Hence the arc on the limb, BC, although only the sixth part of a circle, is divided as if it were 120°, on account of its double being required as the measure of CAB, and it is generally extended to 140°.

The annexed figure represents a sextant of TROUGHTON'S construction, having a double frame, AA, connected by pillars, *a a*, &c. thus uniting strength with lightness. The arc, BC, is generally graduated to 10' of a degree, commencing near the

end, C, and it is numbered towards B. The divisions are also continued on the other side of zero, towards C, forming what is called the arc of excess, which is useful in determining the index error of the instrument, as will be explained hereafter. The limb is subdivided by the vernier, E, into $10''$, the half of which (or $5''$) can be easily estimated: this small quantity is easily distinguishable by the aid of the microscope, H, and its reflector, *b*, which are connected by an arm with the index, IE, at the point, *c*, round which it turns as a centre, affording the means of examining the whole vernier, the connecting arm being long enough to allow the microscope to pass over the whole length of it.



To the index is attached a clamp to fasten it to the limb, and a tangent screw, J, (in the plate, the clamp is concealed from view) by which the index may be moved any small quantity, after it is clamped, to render the contact of the objects observed more perfect than can be done by moving it with the hand

alone. The upper end, I, terminates in a circle, across which is fixed the silvered-index glass, F, over the centre of motion, and perpendicular to the plane of the instrument. To the frame at G is attached a second glass, called the horizon-glass, the lower half of which only is silvered: this must likewise be perpendicular to the plane of the instrument, and in such a position that its plane shall be parallel to the plane of the index-glass, F, when the vernier is set to 0° (or zero) on the limb, BC. A deviation from this position constitutes the index error before spoken of.

The telescope is carried by a ring, L, attached to a stem, e, called the up-and-down piece, which can be raised or lowered by turning the milled screw, M: its use is to place the telescope so that the field of view may be bisected by the line on the horizon-glass that separates the silvered from the unsilvered part. This is important, as it renders the object seen by reflection, and that by direct vision equally bright; two telescopes and a plain tube, all adapted to the ring, L, are packed with the sextant, one showing the objects erect, and the other inverting them; the last has a greater magnifying power, showing the contact of the images much better. The adjustment for distinct vision is obtained by sliding the tube at the eye-end of the telescope in the inside of the other; this also is the means of adapting the focus to suit different eyes. In the inverting telescope are placed two wires, parallel to each other, and in the middle of the space between them the observations are to be made, the wires being first brought parallel to the plane of the sextant, which may be judged of with sufficient exactness by the eye. When observing with this telescope, it must be borne in mind, that the instrument must be moved in a contrary direction to that which the object appears to take, in order to keep it in the field of view.

Four dark glasses, of different depths of shade and colour, are placed at K, between the index and horizon glasses; also

three more at N, any one or more of which can be turned down to moderate the intensity of the light, before reaching the eye, when a very luminous object (as the sun) is observed. The same purpose is effected by fixing a dark glass to the eye-end of the telescope: one or more dark glasses for this purpose generally accompany the instrument. They however are chiefly used when the sun's altitude is observed with an artificial horizon, or for ascertaining the index error, as employing the shades attached to the instrument for such purposes, would involve in the result, any error which they might possess. The handle, which is shewn at O, is fixed at the back of the instrument. The hole in the middle is for fixing it to a stand, which is useful when an observer is desirous of great steadiness.

OF THE ADJUSTMENTS.

THE requisite adjustments are the following: the index and horizon-glasses must be perpendicular to the plane of the instrument, and their planes parallel to each other when the index division of the vernier is at 0° on the arc, and the optical axis of the telescope must be parallel to the plane of the instrument. We shall speak separately of each of these adjustments.

To examine the Adjustment of the Index-glass.

Move the index forward to about the middle of the limb, then, holding the instrument horizontally with the divided limb from the observer, and the index-glass to the eye, look obliquely down the glass, so as to see the circular arc, by direct view and by reflection, in the glass at the same time; and if they appear as one continued arc of a circle, the index-glass is in adjustment. If it requires correcting, the arc will appear broken where the reflected and direct parts of the limb meet. This in a well made instrument is seldom the case, unless the sextant has been exposed to rough treatment. As the glass is in the first instance set right by the maker, and

firmly fixed in its place, its position is not liable to alter, therefore no direct means are supplied for its adjustment.

To examine the horizon-glass, and set it perpendicular to the Plane of the Sextant.

The position of this glass is known to be right, when by a sweep with the index, the reflected image of any object passes exactly over or covers its image as seen directly; and any error is easily rectified by turning the small screw, *i*, at the lower end of the frame of the glass.

To examine the Parallelism of the Planes of the two Glasses, when the Index is set to Zero.

This is easily ascertained; for, after setting the zero on the index to zero on the limb, if you direct your view to some object, the sun for instance, you will see that the two images (one seen by direct vision through the unsilvered part of the horizon-glass, and the other reflected from the silvered part) coincide or appear as one, if the glasses are correctly parallel to each other; but if the two images do not coincide, the quantity of their deviation constitutes what is called the index error. The effect of this error on an angle measured by the instrument is exactly equal to the error itself: therefore, in modern instruments, there are seldom any means applied for its correction, it being considered preferable to determine its amount previous to observing, or immediately after, and apply it with its proper sign to each observation. The amount of the index error may be found in the following manner: clamp the index at about 30 minutes to the left of zero, and looking towards the sun, the two images will appear either nearly in contact or overlapping each other; then perfect the contact, by moving the tangent-screw, and call the minutes and seconds denoted by the vernier, the reading on the arc. Next place the index about the same quantity to the right of zero, or on the arc of excess, and make the contact of the two images

perfect as before, and call the minutes and seconds on the arc of excess* the reading off the arc; and half the difference of these numbers is the index error; additive when the reading on the arc of excess is greater than that on the limb, and subtractive when the contrary is the case.

EXAMPLE.	'	"
Reading on the arc,.....	31	56
„ off the arc,.....	31	22
Difference,	<u>0</u>	<u>34</u>
Index error,..... = —	<u>0</u>	<u>17</u>

In this case the reading on the arc being greater than that on the arc of excess, the index error, = 17 seconds, must be subtracted from all observations taken with the instrument, until it be found, by a similar process, that the index error has altered. One observation on each side of zero is seldom considered enough to give the index error with sufficient exactness for particular purposes; it is usual to take several measures each way; “and half the difference of their means will give a result more to be depended on than one deduced from a single observation only on each side of zero.” A proof of the correctness of observations for index error is obtained by adding the above numbers together, and taking one-fourth of their sum, which should be equal to the sun’s semi-diameter, as given in the Nautical Almanac. When the sun’s altitude is low, not exceeding 20° or 30°, his horizontal instead of his perpendicular diameter should be measured, (if the observer intends to compare with the Nautical Almanac, otherwise there is no necessity); because the refraction at such an altitude affects the lower border (or limb) more than the upper, so as to make his perpendicular diameter appear less than his horizontal one,

* When reading off the arc of excess, the vernier must be read backwards, or from its contrary end.

which is that given in the Nautical Almanac: in this case the sextant must be held horizontally.

To make the Line of Collimation of the Telescope parallel to the Plane of the Sextant.

This is known to be correct, when the Sun and Moon, having a distance of 90° or more, are brought into contact just at the wire of the telescope which is nearest the plane of the sextant, fixing the index, and altering the position of the instrument to make the objects appear on the other wire; if the contact still remains perfect, the axis of the telescope is in proper adjustment; if not, it must be altered by moving the two screws which fasten, to the up-and-down piece, the collar into which the telescope screws. This adjustment is not very liable to be deranged.

Having now gone through the principle and construction of the sextant, it remains to give some instructions as to the manner of using it.

It is evident that the plane of the instrument must be held in the plane of the two objects, the angular distance of which is required: in a vertical plane, therefore, when altitudes are measured; in a horizontal or oblique plane, when horizontal or oblique angles are to be taken. As this adjustment of the plane of the instrument is rather difficult and troublesome to the beginner, he need not be surprised nor discouraged, although his first attempts may not answer his expectations. The sextant must be held in the right hand, and as slack as is consistent with its safety, for in grasping it too hard the hand is apt to be rendered unsteady.

When the altitude of an object, the sun for instance, is to be observed, the observer, having the sea horizon before him, must turn down one or more of the dark glasses, or shades, according to the brilliancy of the object; and directing his sight to that part of the horizon immediately beneath the sun, and holding the instrument vertically, he must with the left hand lightly slide the index forward, until the image of the

sun, reflected from the index-glass, appears in contact with the horizon, seen through the unsilvered part of the horizon-glass. Then clamp it firm, and gently turn the tangent-screw, to make the contact of the upper or lower limb of the sun and the horizon perfect, when it will appear a tangent to his circular disc.* If an artificial horizon is employed, the two images of the sun must be brought into contact with each other; but this will be explained when speaking of that instrument. To the angle read off apply the index error, and then add or subtract the sun's semi-diameter, as given in the Nautical Almanac, according as the lower or upper limb is observed, to obtain the apparent altitude of the sun's centre. Before we can use this observation for determining the time, the latitude, &c., it must be further corrected for refraction and parallax, to obtain the true altitude, subtracting the former and adding the latter; and when the sea horizon is employed, a quantity must also be subtracted for the dip, which is unnecessary when the altitude is taken by means of an artificial horizon.

EXAMPLE.	°	'	"
Obs. alt. of the sun's lower limb,	= 61	13	5
Index error,.....	= -		17
Apparent altitude,.....	= 61	12	48, 0
† { Sun's semi-diameter,	= +	15	46, 9
{ „ parallax,	= +	0	4, 0
Refraction,.....	- 34", 4	} = 61	28 38, 9
Dip of the horizon, for an } elevation of 18 feet, ... }	- 4 3, 0	} = -	4 37, 4
True altitude of the sun's centre, ...	= 61	24	1, 5

* If the observer knows his latitude approximately, he may find the meridional altitude nearly, to which he may previously set his instrument; when he will not only find his object more easily, but have only a small quantity to move the index to perfect the observation.

Take from the Nautical Almanac the declination of the object, and if it be of the same name with the latitude, add it to the co-latitude; if of a different name, subtract it; the sum or difference will be the meridian altitude.

† An observation of a star requires no correction for either parallax or semi-diameter.

If the observer is ignorant of the precise moment of the object's being on the meridian, he should, by a slow and gradual motion of the tangent-screw, keep the observed limb in contact with the horizon as long as it continues to rise; and immediately on the altitudes appearing to diminish, cease from observing, and the angle then read on the instrument will be the meridian altitude.

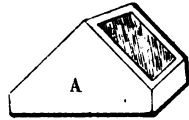
The angular distances of terrestrial objects are measured by the sextant in the same manner as those of celestial ones; but if the objects are not in the same horizontal plane, a reflecting instrument will not give their horizontal angular distance. But this may be obtained nearly by measuring their angular distances from an object in or near the horizon, which subtends a great angle with both, and the sum, or the difference of the angles so measured, will be nearly the required horizontal angle.

Of the sextant, it has been said, that it is in itself a portable observatory; and it is doubtless one of the most generally useful instruments that has ever been contrived, being capable of furnishing data to a considerable degree of accuracy for the solution of a numerous class of the most useful astronomical problems; affording the means of determining the time, the latitude and longitude of a place, &c., for which, and many other purposes, it is invaluable to the Surveyor.

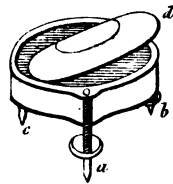
ON THE ARTIFICIAL HORIZON.

WHEN the altitude of a celestial object is to be taken at sea, the observer has the natural (or sea) horizon, as a line of departure; but on shore, he is obliged to have recourse to an artificial one to which his observations may be referred: this consists of a reflecting plane parallel to the natural horizon, on which the rays of the sun or other object falling, are reflected back to an eye placed in a proper position to receive them; the angle between the real object, and its reflected image being then measured with the sextant, is double the altitude of the object above the horizontal plane.

Various natural as well as artificial reflecting surfaces have been made by mechanical arrangements, to afford the means of obtaining double angles: such as pouring water, oil, treacle, or other fluid substances into a shallow vessel; and to prevent the wind giving a tremulous motion to its surface, a piece of thin gauze, talc, or plate-glass, whose surfaces are perfectly plane and parallel, may be placed over it, when used for observation. But the most accurate kind of artificial horizon is that in which fluid quicksilver forms the reflecting surface, the containing vessel being placed on a solid basis, and protected from the influence of the wind. The adjoining figure represents an instrument of this kind. The mercury is contained in an oblong wooden trough, placed under the roof A, in which are fixed two plates of glass whose surfaces are plane and parallel to each other. This roof effectually screens the surface of the metal from being agitated by the wind, and when it has its position reversed at a second observation, any error occasioned by undue refraction at either plate of glass will be corrected.

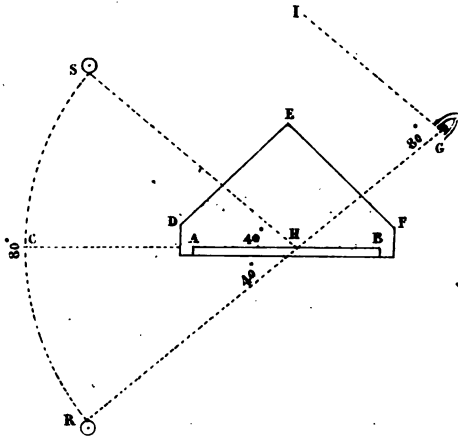


Another and more portable contrivance for an artificial horizon, is represented in the following figure, which consists of a circular plate of black glass about two inches diameter, mounted on a brass stand, half an inch deep, with three foot-screws, *a*, *b*, *c*, to set the plane horizontal; the horizontality being determined thus by the aid of a short spirit-level, *d*, having under the tube a face ground plane on which it lies in contact with the reflecting surface; place the level on the glass in a direction parallel to the line joining two of the three foot-screws, as *a* and *b*, then move one of these screws till the bubble remains in the middle of the tube in both the reversed positions of the level, and the plate will be horizontal in that direction; then place the level



We will conclude this Chapter with an illustration of the method of observing altitudes with an artificial horizon; and a few lines explanatory of Parallax and Refraction:

Let AB represent the surface of the quicksilver contained in a wooden trough, whose plane is continued to C; DEF, the roof, in which are fixed two plates of glass, DE and EF, whose surfaces are plane and parallel to each other: and ☉ the sun at S,



whose altitude is required. Now the ray SH, proceeding from the sun's lower limb to the surface of the quicksilver, will be reflected thence to the eye in the direction HG, and the upper limb of the sun's image, reflected from the quicksilver, will appear in the line GH, continued to R; and it is a well known principle in catoptrics, that the angle of incidence, SHA or SHC, is equal to the angle of reflection, GHB; and as the angle AHR, or CHR, is the opposite angle of GHB, it is, therefore, equal to it, and to the angle SHC, the altitude of the sun's lower limb above the horizontal plane: so that, if we suppose the angle SHR, measured by a sextant, to be 80° , the altitude of the sun's lower limb will be 40° , subject to the corrections, as above.

In the example given of observing an altitude of the sun, its semi-diameter is added. The apparent diameter of the sun, moon, &c., is the angle under which they appear to an observer situated on the earth; the amount of which depends upon the real magnitude of the object, and its distance from the observer. The sun's semi-diameter is given in the Nautical Almanac. Its mean semi-diameter is $16'$, which is the quantity used in

common practice, as it never varies more than half a minute from that amount.

The situation of a celestial body, when viewed from the surface of the earth, is called its *apparent* place, and that part of the heavens where it would be seen, if observed at the same time from the *centre* of the earth, is called its *true* place. The difference between the true and apparent places is termed the *Parallax* of the object. The parallax of an object is greatest at the horizon, and gradually diminishes as the body rises above the horizon, until it comes to the zenith, where the parallax vanishes. It is evident that the altitude of an object seen from the earth's surface, is less than it would be if seen from the centre: hence, the parallax is to be added to the apparent altitude, in order to obtain the true altitude. The sun's mean horizontal parallax is $8\frac{3}{4}''$.

The third correction for an altitude of the sun, is on account of *Refraction*. The rays of light which proceed from a celestial body, on entering the atmosphere in an oblique direction are bent out of their rectilinear course, and incline more and more towards the centre of the earth as they pass deeper into the atmosphere, and hence enter the eye of an observer in a different direction from that of the object, and make it appear higher than its real place. And the difference between the real and apparent places of the heavenly bodies, as affected by the passage of the rays of light through the atmosphere, is called the *Refraction* of the object. The more obliquely the rays enter the atmosphere, the more they will be bent out of their rectilinear course, and hence the greater the refraction: consequently, refraction is greatest at the horizon, and ceases at the zenith. Refraction is always to be subtracted from the apparent altitude of an object, because the effect of refraction is to cause bodies to appear higher than they really are; so much so, that the sun, stars, &c. may actually be below the horizon, when they appear above it. Tables of refraction are given in the Appendix.

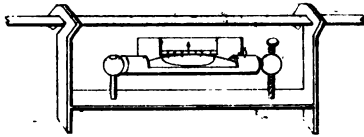
CHAPTER V.

THE SPIRIT LEVEL.

CERTAIN parts of the capital instruments used in surveying and in astronomical observations, require to be adjusted in truly horizontal positions; and, to arrive at this adjustment, one or more subsidiary instruments, called spirit levels, are attached to such principal instruments. The spirit level, attached to a good telescope, furnished with a compass, and such means of correct adjustment, as we shall presently describe, becomes also itself a capital instrument, being used in that department of surveying, termed levelling, which consists in measuring the vertical distances between various stations.

The spirit level consists of a glass tube, differing from the cylindrical form by having its diameter largest in the middle, and decreasing slightly and with great regularity from the middle to the ends. The tube is nearly but not quite filled with spirits of wine, thus leaving in it a bubble of air, which rises to the highest part of the tube, so as to have its two ends equally distant from the middle, when the instrument is in adjustment. The tube is generally fitted into another tube of metal, and attached to a frame terminating in angular bearings, by which the level can either be suspended from, or else be stood upon, cylindrical pivots. When, however, the level forms a permanent part of any instrument, the manner of attaching it is modified to suit the particular form of the instrument to which it is attached. A small and accurately divided scale is attached to the best instruments, or otherwise a scale is scratched upon the glass tube itself.

The annexed figure is a representation of such a level as is used for levelling the axis of the best astronomical instruments. It is provided with a fixed scale, seen in the figure, and is suspended by means of accurately constructed angular bearings.



The following criteria of a good level are extracted from Dr. Pearson's valuable work on Practical Astronomy.

" 1st. The bubble must be long enough, compared with the whole tube to admit of quick displacement, and yet not too long to admit of its proper elongation by low temperature.

" 2nd. The curve must be such, that the sensibility and uniform run of the bubble will indicate quantities sufficiently minute, while those quantities correspond exactly to the changes of inclination, as read on the graduated limb of the instrument of which it forms a part.

" 3rd. The bubble must keep its station when the angles are moved a little round the pivots of suspension.

" 4th. The opposite ends of the bubble must vary alike in all changes of temperature, or, in other words, the ends of the bubble must elongate or contract alike in opposite directions, so that the middle point may always be stationary.

" 5th. The angles of the metallic end-pieces must be so nicely adjusted, that reversion on horizontal pivots that are equal, will not alter the place of the bubble.

" 6th. The distance between the two zeros of a fixed scale, when such a graduated scale is used, should be equal to the length of the bubble at the temperature of 60° of Fahrenheit's scale, and should be marked at equal distances from the visible ends of the glass tube. Then, as the bubble lengthens

by cold, or shortens by heat, its extreme ends may always be referred to these fixed marks, 0, 0, on the scale, and will fall either within, upon, or beyond them, according to the existing temperature. The number of subdivisions of the scale that each end of the bubble is standing at, counted from the fixed zero marks, at the instant of finishing an observation, must always be noted, that an allowance may be made for the value of the deviation in seconds, or as the case may require.

“7th. When the two ends of the bubble are not alike affected by a change of temperature, the scale should be detached, and adjustable to the new zero points, by an inversion of the level.

“8th. When the scale has only one zero at its centre, which is a mode of dividing the least liable to misapprehension, the positions must be reversed at each observation, and both ends of the bubble read in each position; for in this case, if any change has taken place in the true position of this zero, the resulting error will merge in the reduction of the observation.”

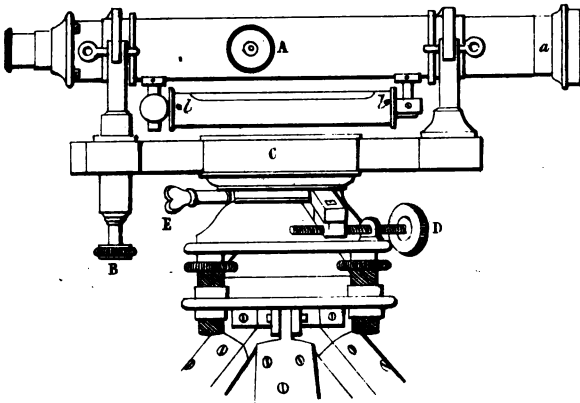
We proceed now to the description of the most accurate instruments for measuring the differences of level, or vertical distances, between different stations.

Of spirit levels for this purpose there are now three in use, namely, the Y level, Troughton's improved level, and Gravatt's level.

The figure on the next page represents the Y level. A, is an achromatic telescope, resting upon two supportors, which in shape resemble the letter Y, and are consequently called the Y's. The lower ends of these supportors are let perpendicularly into a strong bar, which carries a compass box, C. This compass box is convenient for taking bearings, and has a contrivance for throwing the needle off its centre, when not in use. One of the Y supportors is fitted into a socket, and can be raised or lowered by the screw B.

Beneath the compass box, which is generally in one piece with the bar, is a conical axis passing through the upper of

THE Y LEVEL



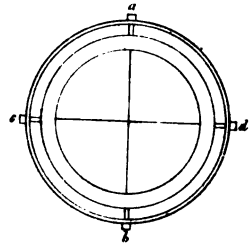
two parallel plates, and terminating in a ball supported in a socket. Immediately above this upper parallel plate is a collar, which can be made to embrace the conical axis tightly by turning the clamping screw E, and a slow horizontal motion may then be given to the instrument by means of the tangent screw D. The two parallel plates are connected together by the ball and socket already mentioned, and are set firm by four mill-headed screws, which turn in sockets fixed to the lower plate, while their heads press against the under side of the upper plate, and thus serve the purpose of setting the instrument up truly level.

Beneath the lower parallel plate is a female screw, adapted to the staff-head, which is connected by brass joints with three mahogany legs, so constructed, as to shut together, and form one round staff, a very convenient form for portability, and, when opened out, to make a firm stand, be the ground ever so uneven.

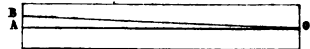
The spirit level *ll* is fixed to the telescope by a joint at one end, and a capstan-headed screw at the other, to raise or depress it for adjustment.

In looking through a telescope a considerable field of view is embraced; but the measurements indicated by any instrument, of which the telescope may form a part, will only have reference to one particular point in this field of view, which particular point is considered as the centre of this field of view. We must therefore place some fixed point in the field of view, and in the focus of the eye-piece, and the point to which the measurement will have reference will be that point of the object viewed, which appears to be coincident with this fixed point, or which, as the technical phrase is, is bisected by the fixed point.

The intersection of two fixed lines will furnish us with such a fixed point, and consequently two lines of spider's web are fixed at right angles to each other in the focus of the eye-piece. They are attached by a little gum to a brass ring of smaller dimensions than the tube of the telescope, and which is fixed to the tube by four small screws, *a, b, c, d*. If the screw, *d*, be eased, while at the same time *c* is tightened, the ring will be moved to the right; but, if *c* be eased and *d* tightened, the ring will be moved to the left; and in a like manner it may be moved up or down by means of the screws *a* and *b*.



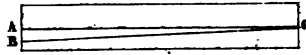
When the instrument is in adjustment, the axis of the tube of the telescope is set truly horizontal by means of the level beneath it, and the line of observation ought consequently to be parallel to this axis. Let *A* represent the proper position of the intersection of the cross wires, and *OA*, the direction of the axis of a pencil of light passing through the object-glass and coming to its focus at *A*. Then, the axis of the tube of the telescope being set truly horizontal, the line *AO* is also truly horizontal, and every point bisected by the inter-



section of the cross-wires will be situated on the prolongation of the horizontal line AO.

Suppose now the position of the diaphragm carrying the cross-wires to have become deranged, so that the point of intersection is moved to B, then every point bisected by the intersection of the cross-wires will be on the prolongation of the line BO, and will consequently be below the true level point on the line AO.

Let now the telescope be turned half round in the Y's, and let the annexed figure represent it in its new position; then, in this new position of the telescope, the prolongation of the line BO will rise above the prolongation of the level



line AO, and, at the same distance from the telescope, the point now bisected by the intersection of the cross-wires will be as much above the true level point on the line AO as the point before bisected by them was below it. The true level point is therefore midway between the two points observed in the two positions of the telescope, and the diaphragm carrying the cross-wires is to be moved by means of the screws *a, b, c, d*, till their point of intersection coincides with that true level point. The telescope is then to be again turned round upon the Y's, and, if the same point be still bisected by the intersection of the cross-wires, they are in their proper position; but, if not, the same method of adjustment must be repeated, till the same point is bisected by the intersection of the cross-wires in every position of the telescope.

This error of derangement has a technical denomination. The line OA, or OB, from O to the point of intersection of the cross-wires, is called the *line of collimation*, and the error arising from their derangement, which we have shown the method of detecting and correcting, is called the *error of collimation*.

When the image of the object viewed, formed by the object-glass, either falls short off, or beyond the place of the cross-wires, the error arising from this cause is called *parallax*.

The existence of parallax is determined by moving the eye about, when looking through the telescope, observing whether the cross-wires change their position, and are fluttering and undefined.

To correct this error, first adjust the eye-piece, by means of the movable eye-piece tube, till you can perceive the cross-wire clearly defined, and sharply marked against any white object.

Then by moving the milled head screw A, at the side of the telescope, the internal tube *a* is thrust outwards or drawn inwards, until you obtain the proper focus, according to the distance of the object, and you are enabled at once to see clearly the object, and the intersection of the wires, clearly and sharply defined, before it. The existence of parallax is very inconvenient, and, where disregarded, has frequently been productive of serious error. It will not always be found sufficient to set the eye-glass first, and the object-glass afterwards. The setting of the object-glass, by introducing more distant rays of light, will affect the focus of the eye-glass, and produce parallax or indistinctness of the wires, when there was none before. The eye-piece must, in this case, be adjusted again.

Generally, when once set for the day, there is no occasion for altering the *eye-glass*, but the *object-glass* will of course have to be altered at every change of distance of the object.

In adjusting the instrument, the parallax should be first corrected, and then the error of collimation. The line of collimation being thus brought to coincide with the axis of the tube of the telescope, two further adjustments are necessary: the first to adjust the bubble tube, so that it may truly indicate when the axis of the telescope is horizontal; and the second to set the axis of the telescope perpendicular to the vertical axis round which the instrument turns.

To adjust the Bubble Tube.—Move the telescope till it lies in the direction of two of the parallel plate screws, and by giving motion to these screws bring the air bubble to the centre of its run. Now reverse the telescope carefully in the Y's, that is, turn it end for end, and should the bubble not

settle at the same point of the tube as before, it shows that the bubble tube is out of adjustment, and requires correcting. The end to which the bubble retires must then be noticed, and the bubble made to return one-half the distance by turning the parallel plate screws, and the other half by turning the capstan-headed screw at the end of the bubble tube. The telescope must now again be reversed, and the operation be repeated, until the bubble settles at the same point of the tube, in the centre of its run, in both positions of the instrument. The adjustment is then perfect, and the clips which serve to confine the telescope in the Y's should be made fast.

Lastly, to set the Axis of the Telescope perpendicular to the Vertical Axis round which the Instrument turns.—Place the telescope over two of the parallel plate screws, and move them, unscrewing one while screwing up the other, until the bubble of the level settles in the centre of its run; then turn the instrument half round upon the vertical axis, so that the contrary ends of the telescope may be over the same two screws, and, if the bubble does not again settle at the same point as before, half the error must be corrected by turning the screw B, and the other half by turning the two parallel plate screws, over which the telescope is placed. Next turn the telescope a quarter round, that it may lie over the other two screws, and repeat the process to bring these two screws also into adjustment; and when, after a few trials, the bubble maintains exactly the same position in the centre of its run, while the telescope is turned all round upon the axis, this axis will be truly vertical, and the axis of the telescope, being horizontal by reason of the previous adjustment of the bubble tube, will be perpendicular to that vertical axis, and remain truly horizontal, while the telescope is turned completely round upon the staves. The adjustment is therefore perfect.

The object of the above adjustments is to make the line of collimation move round in a horizontal plane, when the instrument is turned round its vertical axis, and the methods above explained suppose that the telescope itself is constructed

with the utmost perfection, so that the axis of the tube carrying the object-glass is always in the same straight line with the axis of the main tube, which carries the diaphragm with the cross-wires. If this perfection in the construction of the instrument does not exist, the line of collimation will vary, as the tube carrying the object-glass is thrust out, and drawn in, to adjust the focus for objects of different distances. What is really required, then, is that the cross-wires be so adjusted that the line of collimation may be in the same straight line with the line in which the centre of the object-glass is moved, and that the bubble of the level be at the centre of its run, when this line of collimation is directed to view objects, at the same level, or at the same distance from the centre of the earth.

We are indebted to Mr. Gravatt, of whose level we shall hereafter speak, for a method of collimating, which satisfies the above requirements, and removes any error arising from imperfection in the slide of the telescope, while at the same time the line of collimation is set with the end at the object-glass, slightly depressed, instead of exactly horizontal, so as to remove or nearly so, the errors arising from the curvature of the earth, and the horizontal refraction.

To examine and correct the Collimation by Mr. Gravatt's Method.—"On a tolerably level piece of ground drive in three stakes at intervals of about four or five Chains, calling the first stake *a*, the second *b*, and the third *c*.

"Place the instrument half way between the stakes *a* and *b*, and read the staff *A*, placed on the stake *a*, and also the staff *B*, placed on the stake *b*; call the two readings *A'* and *B'*; then, although the instrument be out of adjustment,* yet the points read off will be equidistant from the earth's centre, and consequently level.

* The axis of the instrument is to be set vertical by means of the parallel plate screws, by placing the telescope over each pair alternately, and moving them, until the air bubble remains in the same position, when the instrument is turned half round upon its axis.

“ Now remove the instrument to a point half-way between *b* and *c*. Again read off the staff *B*, and read also a staff placed on the stake *c*, which call staff *C* (the one before called *A* being removed into that situation). Now, by adding the difference of the readings on *B* (with its proper sign) to the reading on *C*, we get three points, say *A'*, *B'*, and *C'*, equidistant from the earth's centre, or in the same true level.

Place the instrument at any short distance, say half a Chain beyond it, and, using the bubble merely to see that you do not disturb the instrument, read all three staffs, or to speak more correctly, get a reading from each of the stakes, *a*, *b*, *c*; call these three readings *A''*, *B''*, *C''*. Now, if the stake *b* be half-way between *a* and *c*,* then ought $C'' - C' - (A'' - A')$ to be equal to $2 [B'' - B' - (A'' - A')]$; but if not, alter the screws which adjust the diaphragm, and consequently the horizontal spider line, or wire, until such be the case; and then the instrument will be adjusted for collimation.

“ To adjust the spirit bubble without removing the instrument, read the staff, *A*, say it reads *A'''*, then adding $(A''' - A')$ with its proper sign to *B'* we get a value, say *B'''*.”

“ Adjust the instrument by means of the parallel plate screws†, to read *B'''* on the staff *B*.

“ Now, by the screws attached to the bubble tube, bring the bubble into the centre of its run.

“ The instrument will now be in complete practical adjustment for level, curvature, and horizontal refraction, for any distance not exceeding ten Chains, the maximum error being only $\frac{1}{1000}$ th of a foot.”

Before making observations with this instrument, the adjustments should be carefully examined and rectified, after

* Whatever be the distances between the stakes *a*, *b*, and *c*, the following proportions ought to hold, viz. :—

The distance from *a* : *b* : the distance *a* to *c* :: $B'' - B' - (A'' - A')$: $C'' - C' - (A'' - A')$

† If this adjustment be made by the screw *B*, instead of the parallel plate screws, the line of collimation will be brought into its proper position with respect to the vertical axis.

which the screw B should never be touched; but at each station the parallel plate screws alone should be used for setting the axis round which the instrument turns truly vertical, when, in consequence of the adjustments previously made, the line of collimation will be truly level. For this purpose the telescope must be placed over each pair of the parallel plate screws alternately, and they must be moved till the air bubble settles in the middle of the level, and the operation being repeated till the telescope can be turned quite round upon the staff-head, without any change taking place in the position of the bubble, the instrument will be ready to read off the graduations upon the levelling staves, which we proceed to describe.

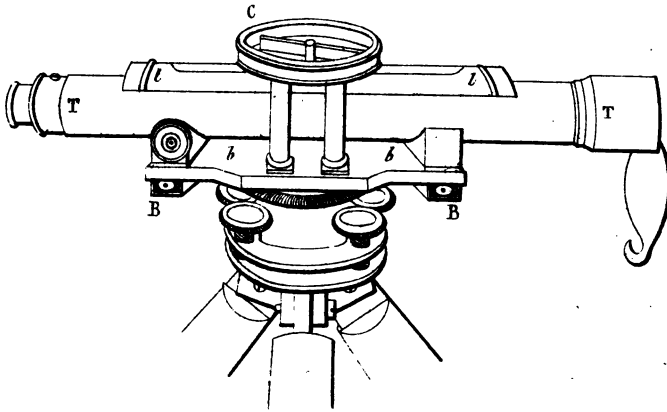
The best constructed levelling staff* consists of three parts, which pack together for carriage in a neat manner, and, when opened out for use, form a staff seventeen feet long, jointed together something after the manner of a fishing-rod. The whole length is divided into hundredths of a foot alternately coloured black and white, and occupying half the breadth of the staff; but for distinctness the lines denoting tenths of feet are continued the whole breadth, every half foot or five-tenths being distinguished by a conspicuous black dot on each side.

In all work where great accuracy is required, the Y level, above described, is preferable to either of the others; but both Troughton's level and Gravatt's level are calculated by their lightness, and by their being less liable to derangement when once properly adjusted, to get rapidly over the ground.

In this level the telescope, T, rests close down upon the horizontal bar, *b, b*, the spirit level, *l, l*, is permanently fixed to the top of the telescope, and does not, therefore, admit of adjustment, and the compass box, C, is supported over the level by four small pillars attached to the horizontal bar. This construction makes the instrument very firm and compact. The staves, staff-head, and parallel plates by which the instrument is supported, and the vertical axis upon which it

* This staff was first introduced into use by William Gravatt, Esq.

TROUGHTON'S LEVEL



turns, are of exactly the same construction as have been already described as used for supporting the Y level.

The diaphragm is furnished with three threads, two of them vertical, between which the levelling staff may be seen, and the third, horizontal, gives the reading of the staff by its coincidence with one of the graduations marked upon it. Sometimes a pearl micrometer-scale is fixed on the diaphragm, instead of the wires. The central division on the scale, then, indicates the collimating point, and by its coincidence with a division of the levelling staff gives the required reading of this staff; and the scale serves the purpose of measuring distances approximately, and of determining stations nearly equidistant from the instrument, since at such equal distances the staff will subtend the same number of divisions upon the micrometer-scale.

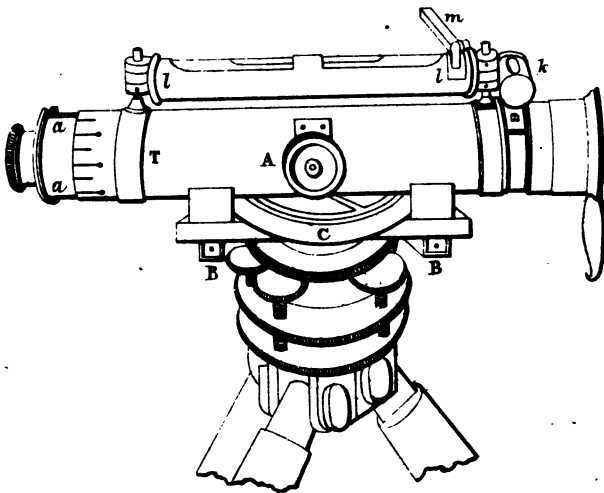
In selecting a level of Troughton's construction, and also in testing and adjusting the collimation subsequently, Mr. Gray's method, already described, is the best to be used; and, when the line of collimation is thus brought into adjustment, if the bubble be far from the centre of its run, the fault can only be remedied by the maker; but, if the bubble settle very nearly

in the centre of its run, the instrument may be deemed a good one, and, the divisions on the glass tube which coincide with the ends of the bubble being noted, the instrument must be set up for use with the bubble in this position.

The line of collimation is set perpendicular to the vertical axis, in the same manner as in the Y level, by means of the capstan screws, B, B, the bubble being made to maintain the requisite position, as above determined, while the instrument is turned completely round on its axis.

MR. GRAVATT'S LEVEL.

THIS instrument is furnished with an object-glass of large aperture and short focal length; and, sufficient light being thus obtained to admit of a higher magnifying power in the eye-piece, the advantages of a much larger instrument are



obtained, without the inconvenience of its length. The diaphragm is carried by the internal tube *a, a*, which is nearly equal in length to the external tube. The external tube *T, T*, is sprung at its aperture, and gives a steady and even motion to

the internal tube a, a , which is thrust out, and drawn in, to adjust the focus for objects at different distances by means of the milled-headed screw A . The spirit level is placed above the telescope, and attached to it by capstan-headed screws, one at either end, by means of which the bubble can be brought to the centre of its run, as in the case of the Y level, when the line of collimation is brought to the proper level by Mr. Gravatt's method of adjustment, already explained.

The telescope is attached to a horizontal bar in a similar manner to Troughton's level, but room is just left between the telescope and the bar for the compass-box.

A cross level, k , is placed upon the telescope at right angles to the principal level l, l , by which we are enabled to set the instrument up at once with the axis nearly vertical. A mirror m , mounted upon a hinge-joint, is placed at the end of the level l, l , so that the observer, while reading the staff, can at the same time see that the instrument retains its proper position—a precaution by no means unnecessary in windy weather, or on bad springy ground.

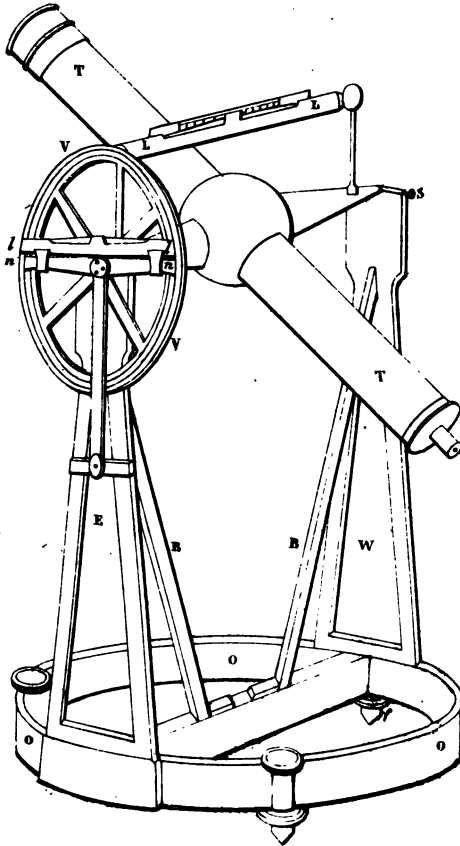
The telescope is attached to the horizontal bar by capstan-headed screws, B, B , as in Troughton's level, by which the line of collimation is set perpendicular to the vertical axis; and the instrument is set up upon parallel plates, as before described, for the Y level.

CHAPTER VI.

THE TRANSIT INSTRUMENT.

REFLECTING instruments, from their portability and the promptitude and facility with which they may be used in all situations, and upon all occasions, are very useful instruments to the Surveyor. The Sextant with an Artificial horizon, and a good chronometer, forms an observatory of itself, with which the latitudes and longitudes of places may be determined to a certain degree of accuracy. In permanent observations the capital angular instruments are placed permanently in the plane of the meridian, and the measurements sought for by their aid are the exact times at which the observed objects pass the meridian, and their angular altitudes or zenith distances, when upon the meridian. The instrument with which the first of these measurements is obtained, is called a *transit instrument*, *transit telescope*, or merely a *transit*. Transits of portable dimensions, besides their use in small or temporary observatories, are found serviceable to the Surveyor, for determining, with the greatest possible accuracy, the true north point, and thence setting out a line in any required direction. The figure in the next page represents a portable transit.

T, T is a telescope formed of two parts, connected by a spherical centre-piece, into which are fitted the larger ends of two cones, the common axis of which is placed at right angles to the axis of the telescope, to serve as the horizontal axis of the instrument. The two small ends of these cones are ground into two perfectly equal cylinders, called *pivots*. The pivots rest upon angular bearings or Y's.



The Y's are supported upon the standards E and W, of which E may be called the eastern, and W the western standard; one of the Y's is fixed in a horizontal groove, on the western standard, so that by means of the screw S, one end of the axis may be pushed a little forwards or backwards, and a small motion in azimuth be thus communicated to the telescope.* The standards, E and W, are fixed by screws upon

* The large transits in permanent observations have their Y's placed in two dove-tailed grooves, one horizontal, and the other vertical. By means of the latter, one end of the axis may be raised or depressed; but in the portable transit the same object is attained by turning one of the foot screws upon which the entire instrument rests.

a brass circle, O, O, and steadied by oblique braces, B, B, which spring from the cross-piece, C.

On one end of the axis is fixed, so as to revolve with the axis, a vertical circle, V, V; and a double index bar, furnished with a spirit level *l, l*, to set it horizontal, carries two verniers, *n, n*, adapted to the vertical circle, and shewing the angle of elevation of the telescope. The index-bar is fixed in its position by the clamping screw, C, and can be fixed upon either the eastern or western standard, at pleasure, while the telescope, with its attached circle, can also be lifted out of, and have its position reversed in the Y's. The pivot which does not carry the vertical circle, is pierced, and allows the light from a lamp to fall upon a plane speculum, fixed, in the spherical centre-piece, on the axis of the telescope, and inclined to this axis at an angle of 45° . The light is thus thrown directly down the telescope, and illuminates the wires of the diaphragm, placed in the principal focus of the telescope. Of these wires one is horizontal; and a vertical wire, intersecting it in the centre of the field of view, gives by its intersection with it, the collimating point. There are then, other vertical wires arranged in pairs equi-distant from the central vertical wires, so that we have either three or five, or seven vertical wires, the most common number being five. The lamp has a contrivance for regulating the quantity of light thrown into the telescope, by turning a screw, so that the light from a small star may not be overpowered by the superior light of the lamp.

The requisites of a good instrument, are—1stly, that the telescope be of the best quality; 2ndly, that the feet screws act well and remain steady; 3rdly, that all the screws, by which the instrument is put together, are turned home, and remain so, after the instrument has been shaken by carriage; 4thly, that the length of the axis be just sufficient to reach from one Y to the other, without either friction or liberty; 5thly, that the lamp be held so as not to require adjustment for position; 6thly, that the screws of adjustment of the diaphragm, and Y's,

be competent to give security of position to the parts adjusted by them; 7thly, that the metallic parts be free from flaws in casting, and that the pivots be formed of hard bell metal and incapable of rusting.

The principal adjustments of the Transit are three:

1st. To make the axis on which the telescope moves, horizontal.

2nd. To make the line of collimation move in a great vertical circle, by setting it perpendicular to the horizontal axis.

3rd. To make it move in that vertical circle, which is the meridian.

To make the Axis Horizontal.—Apply to the pivots the large level, L,L, which is supplied with the instrument for this purpose. Bring the air bubble to the centre of its run, by turning the foot screw, *f*. Turn the level end for end, and if the air bubble retains its position, the axis is horizontal, but, if not, it must be brought back half by the foot screw, *f*, and the other half by turning the small screw at one end of the level. Repeat the operation till the bubble retains the same position in both positions of the level, and the axis will be horizontal.

To adjust the Line of Collimation in Azimuth.—Direct the telescope to some distant, small, and well-defined object, and bisect it by one extremity of the middle vertical wire, giving the telescope the azimuthal motion necessary for this purpose by turning the screw S. By elevating or depressing the telescope, examine whether the object is bisected by every part of the middle vertical wire; and, if not, loosen the screws which hold the eye-end of the telescope in its place, and turn the end round very carefully till the error is removed. Lift the transit off the Y's, and reverse it, so that the end of the axis, which was upon the eastern Y, may now be upon the western, and *vice versa*; and, if the object is still bisected by the central vertical wire, the collimation in azimuth is perfect; but, if not, move the centre of the cross-wires half-way towards the object by turning the small screws which hold the

diaphragm, and if this half distance has been correctly estimated, the adjustment will be accomplished. Again, bisect the object by the centre of the cross-wires by turning the azimuthal screw, S, and repeat the operation, till the object is bisected by the centre of the cross-wires in both positions of the instrument, and the adjustment will be known to be perfect.*

To adjust the Transit to the Meridian.—The line of collimation by reason of the previous adjustment describes a vertical circle, and, therefore, bisects the zenith, which is one point in the meridian. If, then, we can make it also bisect another point in the meridian, it will move entirely in the meridian. Compute from the tables in the Nautical Almanack, the time of Polaris coming to the meridian, and at the computed time bisect the star by the middle vertical wire, and the transit will be very nearly adjusted to the meridian.

To make the great vertical circle described by the line of collimation more nearly coincident with the meridian, let the intervals between the successive passages of Polaris across the meridian be observed, as indicated by the instrument. Then, if the interval between the inferior and superior passage be equal to the interval between the superior and inferior, the adjustment to the meridian is perfect; but if the interval between the inferior and superior passage be less than the interval between the superior and inferior, the circle described by the line of collimation deviates to the eastward of the true meridian, from the zenith to the north point of the horizon, and to the westward, from the zenith to the south point of the horizon; while if the interval between the inferior and superior passage be the greater, the deviation is in the contrary directions.

Let δ be the observed difference of the intervals from twelve hours, or half the difference between the two intervals in seconds, π the polar distance of the star Polaris, and L the

* The horizontal motion given to the Y, by the azimuthal screw S, forms, evidently, no part of the adjustment for collimation, but only enables us to examine if the adjustment has been made with sufficient exactness.

latitude of the place, then, Z representing the deviation from the meridian in time, the value of Z will be given by the logarithmic formula.

$$\log. Z = \log. \frac{\delta}{2} + \log. \sec. L + \log. \tan. \pi - 20.$$

EXAMPLE.

Place of observation, near Calcutta, Latitude $22^{\circ} 33' 01''$.

Polar distance of Polaris, $1^{\circ} 39' 25''.05$.

Difference of intervals from 12 hours $7^m 22^s = 442^s$.

$$\frac{\delta}{2} = 221 \dots \dots \dots \log. = 2.3443923$$

$$L = 22^{\circ} 33' 01'' \dots \dots \log. \sec. = 10.0345427$$

$$\pi = 1^{\circ} 39' 25''.05 \dots \log. \tan. = 8.4613064$$

$$Z = 6^s. 922 \dots \dots \log. = \underline{\underline{20.8402414}}$$

To determine the value of a revolution of the azimuthal screw, S , the time* of passage of an equatorial star across the middle vertical wire must be noted one day; and then, turning the screw, S , once round, the time of passage must be noted again; and the difference of these times will be the value in time of a revolution of the screw. Suppose the difference thus observed to amount to two seconds, then the value of one complete revolution of the screw, S , is two seconds, and the value of the motion of the adjusting screw being thus obtained, must be reduced to the horizon, by increasing it in the ratio of cosine of latitude to radius, and may then be applied to correct the error of deviation as found above.

A second method founded on the same principles as the preceding, consists in observing the Pole star, and another star, which crosses the meridian near the zenith of the place of observation. The time of passage of such a star, Capella, for instance, when near its superior transit, across the middle wire of the telescope, will differ but very little from the time of passing the true meridian, if the deviation of the instru-

* The time here spoken of, and throughout the description of this instrument, unless otherwise expressly stated, is sidereal, and not mean time.

ment from the meridian be but small. Assume the two times to agree exactly, and the difference between the times of superior transit of Capella and Polaris, will be the difference of the observed right ascensions of these two stars. From this difference subtract the difference of the computed right ascensions of the two stars, and call the result D ; and the deviation will be given by the formula.

$$\log. Z = \log. D + \log. \sin. \pi + \log. \sec. (L + \pi)$$

π being the polar distance of Polaris, and L the latitude of the place of observation. From Capella not having been exactly on the meridian, when on the middle vertical wire, the value of D , as above obtained, is only an approximation to the error of the observed right ascension of Polaris, and the deviation computed from it will be only approximately correct; but, by repeating the operation, the adjustment may be completely perfected.

D is actually the value of the sum of the errors of the observed right ascensions of Capella and Polaris, and hence the value of Z will be correctly given, by so considering it instead of supposing as above, that this error for Capella is zero. The true deviation then is given by the formula.

$$\log. Z = \log. D + \log. \sin. \pi + \log. \sin. \pi' + \log. \operatorname{cosec}. (\pi' - \pi) + \log. \sec. L.$$

π' being the polar distance of Capella.

Using this last formula, the method may be applied to Polaris, and any star distant from the pole, or to any two stars differing from each other not less than 40° in declination. If however, the transit of one star is observed above, and of the other, below the pole, the formula will be

$$\log. Z = \log. D + \log. \sin. \pi + \log. \sin. \pi' + \log. \operatorname{cosec}. (\pi' + \pi) + \log. \sec. L.$$

Considerable advantage may be obtained by selecting two stars, that differ but little in right ascension, as there is then the less probability of error from a change in the rate of the clock, or in the position of the instrument, on which account such methods are to be preferred in temporary observatories, where the stability of the instrument is not to be depended upon for any length of time.

In all the preceding formulæ, the deviation from the meridian is given in time; but, to convert it into angular measure, if desirable, we have only to multiply by 15, and the seconds of time will be converted into seconds of a degree.

When the instrument is by any of the methods explained above, brought into the meridian, a distant mark may be set up in the plane of the meridian, by which the adjustment to the meridian may afterwards be tested.

METHOD OF OBSERVING WITH THE TRANSIT.

THE adjustments having been completed, in making observations with the instrument, the instant of a star's passing the middle vertical wire will be the time of the star's transit; but the time of the star's passing all the five wires must be noted, and the mean of the times, taken as the time of transit, will be a more accurate result than the time observed at the middle wire only.

When the sun is the object observed, the time of the centre of his disc passing the middle wire is the time of transit; but, as it would be impossible to estimate this centre with accuracy, the time of both his limbs coming into contact with each wire in succession is to be noted, and a mean of all these times will be the time of transit required. This mean may be conveniently taken, by writing the observed times of contact of the first and second limbs underneath each other in the reverse order, when the sums of each pair will be nearly equal.

EXAMPLE.

1849 Jan. 23	^s	^s	^h	^m	^s	^s	^s	☉ 1 Limb. ☉ 2 Limb.
	20·4	38·7	11	58	57·0	15·5	33·7	
	42·3	24 0	12	1	5·7	47·2	28·7	
	2·7	2·7	24	0	2·7	2·7	2·4	The sum = 13·2

The time of either limb passing the centre wire is recorded in full, but for the other wires, the seconds only are recorded, as the sums of the several pairs only differ by decimals of a

second. Half the sum of the times at the middle gives, then, the correct time of transit as far as the second, and the decimals are found by removing the decimal point one place to the left in the sum 13.2, which is equivalent to dividing by 10. Then the time of transit, or mean of observations in the above example is $12^{\text{h}} 0^{\text{m}} 1^{\text{s}}.32$. This example is taken from observations made with a large transit; and, if with a smaller instrument the sums of the several pairs of observations should differ by more than a second, it will be necessary to take the sums of both figures of the seconds, and the division by 10, performed as above, will give the last figure of the seconds, as well as the decimals.

In taking transits of the moon the luminous edge alone can be observed, from which the time of transit of the centre must be deduced by the aid of Lunar tables.

In observing the larger planets, one limb may be observed at the first, third, and fifth wires, and the other at the second and fourth, and the mean of these observations will give the transit of the planet's centre.

It will sometimes happen that from the state of weather, or from some other cause, a heavenly body may not have been observed at all the wires; but, if the declination of the body be known, an observation at any one of the wires may be reduced to the central wire, so as to give the time of transit, as deduced from this observation. If an observation be obtained at more than one wire, the mean of the times of passing the centre, as deduced from each wire observed, is to be taken as the time of transit. The reduction to the centre wire is given by the formula,

$$R = V \operatorname{cosec} \pi,$$

$$\text{or } \log. R = \log. V + \log. \operatorname{cosec} \pi;$$

in which R represents the reduction, π the polar distance of the body observed, and V the equatorial interval from the wire, at which the observation has been made, to the central wire. The equatorial intervals for each side wire must, there-

fore, be carefully observed, and tabulated for the purpose of this reduction. The formula $R = V \operatorname{cosec.} \pi$ is only an approximate value of the reduction, and with large instruments, capable of giving results within $0''\cdot05$, a further correction is necessary for bodies within 10° of the pole. The whole reduction in this case is given by the formula,

$$R' = \frac{1}{15} \sin' 15 V \operatorname{cosec.} \pi.$$

The time of any star's passage from one of the side wires to the centre wire being observed, the equatorial interval from that wire to the centre is obtained by multiplying the observed interval by the sine of the star's polar distance; and the equatorial intervals being deduced in this manner from a great many stars, the mean of the results may be considered as very correct values of the equatorial intervals required. No star very near the pole should, however, be taken for this purpose.

USE OF THE PORTABLE TRANSIT.

THE large transits in permanent observatories are used to obtain, with the greatest possible accuracy, the right ascensions of the heavenly bodies, from which, and the meridian altitudes observed by a mural circle, an instrument, consisting of a telescope attached to a large circle, and placed in the plane of the meridian, nearly all the data necessary for every astronomical computation are obtained. For such purposes the small portable transit is not adapted; but it is competent to determine the time to an accuracy of half a second, to determine the longitude by observations of the moon and moon culminating stars, and to determine the latitude by placing it at right angles to the meridian, or in the plane of the prime vertical.*

The transit of the sun's centre gives the apparent noon at the place of observation, and the mean time at apparent noon

* The prime vertical is the great circle which passes through the zenith and the east and west points of the horizon.

is found by subtracting or adding the equation of time, as found in the Nautical Almanack, to 24 hours*. The difference between the mean time, thus found, and the time of the sun's transit, as shown by a clock or chronometer, is the error of the clock or chronometer for mean time at the place of observation.

The time shown by a sidereal clock when any heavenly body crosses the meridian should coincide with the right ascension of that body, as given in the Nautical Almanack. The difference between the time shown by the sidereal clock, at the transit and the right ascension of the body, taken from the Almanack will, therefore, be the error of the clock, +, or too fast, when the clock time is greater than the right ascension, —, or too slow, when it is less.

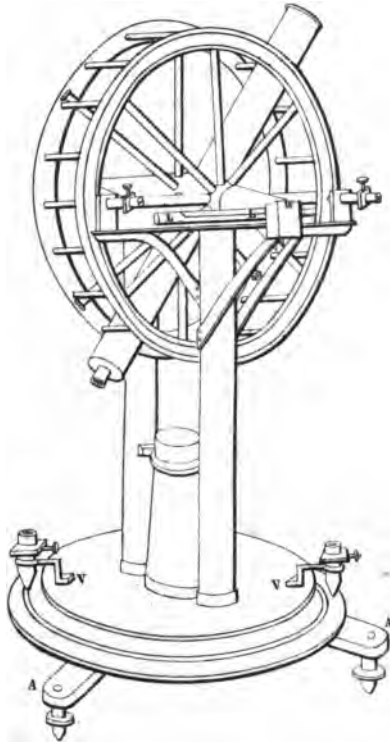
THE PORTABLE ALTITUDE AND AZIMUTH INSTRUMENT.

THE bending of an unbraced telescope renders it unfit for the determination of altitudes; but by placing the telescope between two circles braced together, an instrument may be formed capable of observing both the meridian altitudes and times of transit of the heavenly bodies. The increased weight of the instrument, however, must now be prevented from producing flexure in the horizontal axis, and this has been very ingeniously accomplished by Troughton. By mounting the transit and altitude instrument, as Troughton's transit-circle may be called, upon a horizontal plate or circle having an azimuthal motion round a vertical axis, an instrument is formed by which observations may be made either in or out of the meridian. When constructed of a portable size, the altitude and azimuth instrument may also be used in important sur-

* The astronomical day commences at noon, and contains 24 hours, the hours after midnight being called 13, 14, &c., and the day ends at the next noon. The equation of time is given in the Nautical Almanack for apparent noon at the meridian of Greenwich, and the correction to give the equation of time at any other meridian will be found by multiplying the difference for one hour, as given in the Almanack, by the longitude of the place, estimated in time.

veying operations; for, in fact, it may be considered as a rather large theodolite of superior construction.

The altitude and azimuth instrument may be considered as consisting of three parts; 1st, the tripod carrying the vertical axis about which the instrument turns; 2nd, the horizontal revolving plate carrying the vertical pillars, with their appendages; and 3rd, the vertical circles with the telescope.



The tripod, A, A, is supported by three foot-screws, by which the vertical axis is brought into adjustment, and carries the lower horizontal plate, which is graduated to show the azimuths or horizontal angles. The vertical axis is a solid metallic cone rising from the centre of the tripod to a height about equal to the radius of the horizontal circle.

The upper horizontal plate, or horizontal revolving plate, V, V, carries an index, to point out the graduation, upon the lower horizontal plate, or azimuth circle, which denotes nearly the angle to be read off. The graduations upon the azimuth circle, as well as upon the vertical circle, are subdivided by reading microscopes, the construction and adjustments of which we shall presently explain. The reading microscopes of the azimuth circle are attached to the revolving plate, V, V, which also carries two upright pillars. From the centre of the upper horizontal plate, V, V, rises a hollow brass cone which just fits over, and moves smoothly upon the solid metallic vertical axis rising from the tripod stand. A horizontal brace connects the two upright pillars with one another and with the top of the hollow brass cone, and keeps the pillars firm and parallel to one another. On the top of each pillar a gibbet piece is fixed, projecting beyond the pillars, and upon the extreme ends of these pieces are carried the Y's for supporting the pivots of the horizontal, or transit axis. The Y's are each capable of being raised or lowered by turning a milled-headed screw. The top of one of the pillars carries a cross-piece for supporting the two reading microscopes of the vertical circle; and to this cross-piece is attached the level, L, L, by which the adjustment of the vertical axis is denoted.

The third portion of the instrument consists of the vertical circle and its telescope. This circle consists of two limbs firmly braced together, and preventing any tendency to flexure in the tube of the telescope, by affording it support at the opposite ends of a diameter. One of the limbs only is graduated, and the graduated side is called the face of the instrument, and the clamp and tangent screw, for giving a slow motion to the vertical circle, act upon the ungraduated limb, and are fixed to the vertical pillar on the side of that limb. The horizontal axis which supports the telescope and vertical circle is constructed exactly as the axis of the transit instrument already described; but, as it might press too heavily on

the Y's from the increased load of the vertical circle, a spiral spring, fixed in the body of each pillar, presses up a friction roller against the conical axis with a force which is nearly a counterpoise to its weight. The adjustment of the horizontal axis is denoted by a level, as in the portable transit already described.

ADJUSTMENTS.

Adjustments of the Vertical Axis.—Turn the instrument round till the level, L, L, is over two of the foot-screws, and adjust the level, so that its bubble may retain the same position, when the instrument is turned half round, so that the level is again over the same foot-screws, but in the reverse position. The error at each trial is corrected, as nearly as can be judged, half by the foot-screws, and half by the adjusting screw of the level itself.

Next turn the instrument round 90° in azimuth, so that the level, L, L, may be at right angles to its former positions, and bring the bubble to the same position as before, by turning the third foot-screw. Repeat the whole operation till the result is satisfactory.

Adjustment of the Horizontal Axis.—This adjustment is performed in the same manner, as already described for the Transit instrument (Page 173) with the single exception that one end of the axis is to be raised or lowered, if necessary, by the screw acting upon its Y, and not by moving a foot-screw, which would derange the previous adjustment.

Adjustment of the Circle to its Reading Microscopes.—This is performed by raising or lowering both the Y's equally, so as not to derange the previous adjustment, till the microscopes are directed to opposite points in its horizontal diameter.

Adjustment of Collimation in Azimuth.—Instead of taking the axis out of its bearings and turning it end for end, the whole instrument is turned round in azimuth; but in all other respects the method of performing this adjustment is the same as that already described for the Transit instrument (Page 173).

Adjustment of Collimation in Altitude.—Point the telescope to a very distant object, or star, and, bisecting it by the cross-wires, read off the angle upon the vertical circle denoted by the reading microscopes. Turn the instrument half round in azimuth, and, again bisecting the same object by the cross-wires, read off the angle. One of these readings will be an altitude, and the other a zenith distance,* and their sum, therefore, when there is no error of collimation in altitude, will be 90° . If the sum is not 90° , half its difference from 90° will be the error of collimation in altitude, and this error being added to, or subtracted from, the observed angles, according as the sum of the readings is less or greater than 90° will give the true zenith distance and altitude. The error of collimation in altitude may then be corrected by adjusting the microscopes to read the true zenith distance and altitude, thus found, while the object is bisected by the cross-wires of the telescope.

Use of the Altitude and Azimuth Instrument.—In using the altitude and azimuth instrument, for astronomical purposes, double observations should always be made, with the face first to the east, and then to the west, or *vice versa*, or several observations may be made with the face to the east, and as many with the face to the west, and the mean of the results, reduced to the meridian, taken as the true results. The place for a meridian mark may be determined by the methods already explained when describing the transit instrument, or by observing the readings of the azimuthal circle, or noting the times, when any celestial object has equal altitudes. Since the diaphragm of the telescope is furnished not only with the central horizontal wire, but with other horizontal wires at equal distances above and below it, so that there may be altogether either three or five, or seven horizontal wires, the

* Both the horizontal and vertical circles are usually divided alike into four quadrants, and each quadrant graduated from 0° to 90° , proceeding in the same direction all round the circles.

azimuths and times may be observed, when the object observed is bisected by each of these wires. If a fixed star be the object observed, the mean of the times will give the time of the star's passing the meridian, and the mean of the azimuths will give the reading of the azimuth circle when the star was on the meridian, or the correction to be applied to the readings of the azimuth circle to give the true azimuths. If the sun be the body observed, a correction is necessary on account of the change of his declination, during the intervals between the observations.

The correction for the time, as deduced from a pair of equal altitudes of the sun, is given by the formula,

$$\text{Correction} = \frac{\delta}{720} \times \frac{t}{\sin. 15^\circ \cdot t} (\tan. D \times \cos. 15^\circ \cdot \frac{t}{2} - \tan. L)$$

in which δ represents the variation in the sun's declination from the noon of the day preceding the observations to the noon of the day succeeding:

t represents the interval between the observations expressed in hours and decimals of an hour:

D represents the sun's declination at noon on the day on which the observations are made:

L represents the latitude of the place.

δ is to be reckoned positive when the sun's declination is increasing, and negative when it is decreasing.

The correction for azimuth is given by the formula,

$$\text{Correction} = \frac{1}{2} (D' - D) \sec. \text{lat. cosec. } \frac{15}{2} (T' - T).$$

in which $D' - D$ represents the change of the sun's declination, and $T' - T$ represents the interval in time, } between the observations.

When the sun is advancing towards the North Pole, this correction will carry the middle point towards the west of the approximate south point; but when he is approaching the

South Pole, it will carry the same point towards the east, and must be applied accordingly.

The altitude and azimuth instrument being adapted to observe the heavenly bodies in any part of the visible expanse of the heavens, its powers may be applied at any time to determine the data from which the time, the latitude of the place of observation, or the declination of the body observed, may be at once determined. We subjoin some of the formulæ, adapted to logarithmic computation, connecting the parts of what may be called the *astronomical triangle*, of which the angular points are, the pole, P, the zenith, Z, and the apparent place of the body observed, S.

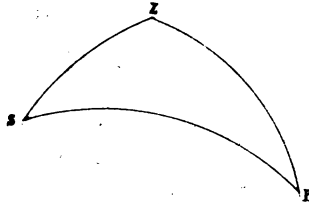
Let PZ, the colatitude of the place, be represented by λ .

PS, the polar distance of the body observed ... π .

ZS, the zenith distance of the body observed ... Z .

ZPS, the hour angle from the meridian h .

PZS, the azimuthal angle..... a .

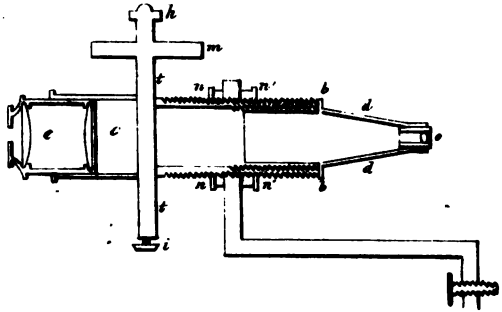


Then we have the following formulæ for determining the time, the latitude, and the declination of the body observed.

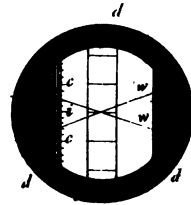
No.	GIVEN.	REQUIRED.	AUXILIARY ANGLES.	FORMULÆ.
1	z, π, λ	h$	.....	\tan \frac{1}{2} h = \sqrt{\frac{\sin \frac{1}{2}(z + \pi - \lambda) \cdot \sin \frac{1}{2}(z + \lambda - \pi)}{\sin \frac{1}{2}(z + \pi + \lambda) \cdot \sin \frac{1}{2}(\pi + \lambda - z)}}$
2	π, λ, α	h	$\tan \phi = \frac{\cot \alpha}{\cos \lambda}$	$\cos (h - \phi) = \frac{\cot \lambda}{\cot \pi \cos \phi}$
3	z, λ, α	h	$\cot \phi = \frac{\cot z}{\cos \alpha}$	$\cot h = \frac{\cot \alpha \sin (\lambda - \phi)}{\sin \phi}$
4	z, π, α	h$	.....	\sin h = \frac{\sin z \sin \alpha}{\sin \pi}$
5	z, π, α	λ	$\tan \phi = \cos \alpha \tan z$	$\cos (\lambda - \phi) = \frac{\cos \pi \cos \phi}{\cos z}$
6	z, π, h	λ	$\tan \phi = \cos h \tan \pi$	$\cos (\lambda - \phi) = \frac{\cos z \cos \phi}{\cos \pi}$
7	z, α, h	λ	$\cot \phi = \frac{\cot z}{\cos \alpha}$	$\sin (\lambda - \phi) = \frac{\cot h \sin \phi}{\cot \alpha}$
8	π, α, h	λ	$\cot \phi = \frac{\cot \pi}{\cos h}$	$\sin (\lambda - \phi) = \frac{\cot \alpha \sin \phi}{\cot h}$
9	z, λ, α	π	$\tan \phi = \cos \alpha \tan z$	$\cos \pi = \frac{\cos z \cos (\lambda - \phi)}{\cos \phi}$
10	z, λ, h	π	$\tan \phi = \cos h \tan \lambda$	$\cos (\pi - \phi) = \frac{\cos z \cos \phi}{\cos \lambda}$
11	z, α, h	π$	.....	\sin \pi = \frac{\sin \alpha \sin z}{\sin h}$
12	λ, α, h	π	$\tan \phi = \frac{\cot \alpha}{\cos \lambda}$	$\cot \pi = \frac{\cot \lambda \cos (h - \phi)}{\cos \phi}$

THE READING MICROSCOPE.

THE first of the annexed figures represents a longitudinal section of this instrument, and the second represents the



field of view, showing the magnified divisions of the limb of the instrument to which the microscope is applied, and the diaphragm, *d, d*, of the microscope, with its comb, *c, c*, and cross-wires, *w, w*. The diaphragm is contained in the box, *t, t*, and consists of two parts moving one over the other, the comb, *c, c*, which is moved by the screw, *i*, at the bottom of the box, for the purpose of adjustment, and the cross-wires, *w, w*, and index, *i*, which are moved over the comb and the magnified image of the limb, by turning the milled head, *h*. The micrometer head, *m*, is attached by friction to the screw turned by the milled head, so that, by holding fast the milled head, the micrometer head can be turned round for adjustment.



e is the eye-piece, which slides with friction into the cell, *c*, so as to produce distinct vision of the spider's lines of the micrometer. The object-glass, *o*, is held by a conical piece, *d, d*, which screws further into, or out of, the body of the instrument, so as to produce distinct vision of the divided limb, to be read by the microscope, and, when adjusted, is held firmly in its place

by the nut, b, b . The microscope screws into a collar, so as to be capable of adjustment with respect to its distance from the divided limb, and, when so adjusted, is held firmly in its place by the nuts, n, n, n', n' .

Adjustments of the Reading Microscope.—Screw the object glass home. Insert the body of the microscope into the collar destined to receive it, and screw home the nuts, n, n and n', n' . Make the diaphragm and spider's lines visible distinctly, by putting the eye-piece, e , the proper depth into the cell, c . Then make the graduated limb also distinctly visible without parallax by turning the nuts, n, n , and n', n' , unscrewing one and screwing up the other till the desired object is attained.

Now bring the point of intersection of the spider's lines upon a stroke of the limb, and turn the micrometer head, m , to zero; then, turning the screw through five revolutions, if the point of intersection of the spider's lines has not moved over the whole of one of the divided spaces on the limb, the object lens must be screwed up to diminish the power by turning the cone, d, d ; and if it has moved over more than one of the divided spaces, it must be unscrewed to increase the power, and then altering the position of the microscope, by turning the nuts, n, n and n', n' , till distinct vision of the limb is again obtained, the measure of the space, moved over by five revolutions of the screw, must be repeated, as before. When, after repeated trials, the result is satisfactory, the three nuts, n, n, n', n' , and b, b , must be screwed tight home, to render the adjustment permanent.

When the microscope has been thus adjusted for distance, the zero of the division on the limb must be brought to the point of intersection of the spider's lines, and the divided head, m , turned, till its zero is pointed to by its index, and then, if the zero on the comb, c, c , be not covered exactly by the index, i , the comb must be moved by turning the screw, i , which enters the bottom of the micrometer box, till its zero is covered by the index pin. The adjustment of the reading

microscope will now be perfect; and the graduated limb to be read by it, being divided at every five minutes, the degree and nearest five minutes of an observed angle will be shown by the pointer or index to this graduated limb; while the number of complete revolutions, and the parts of a revolution, of the screw, in the order of the numbers upon the micrometer head, m , required to bring the point of intersection of the spider's lines upon a division of the graduated limb, will be the number of minutes and seconds, respectively, to be added to the degrees and minutes shown by the index of the circle. The complete revolutions, or minutes, to be added, are shown by the number of teeth the index, i , has passed over from zero, and the parts of a revolution, or seconds and tenths to be added, are pointed out upon the micrometer head, m , by its index.

CHAPTER VII.

ON MATHEMATICAL DRAWING INSTRUMENTS.

IN this branch the limits of our work will not permit us to enter upon all the contrivances that have been invented for facilitating the operations of the draughtsman; but we shall endeavour to describe the constructions and applications of such as are in most general use, and, as far as our space will allow, to exhibit the principles upon which they are founded.

With this view we shall commence with the instruments of the ordinary case of drawing instruments, as sold by any mathematical instrument maker.

ON DRAWING COMPASSES.

THIS instrument consists of two legs movable about a joint, so that the points at the extremities of the legs may be set at any required distance from one another; it is used to transfer and measure distances, and to describe arcs and circles.

The points of the compasses should be formed of well-tempered steel, that cannot easily be bent or blunted, the upper part being formed of brass or silver. The joint is framed of two substances; one side being of the same material as the upper part of the compasses, either brass or silver, and the other of steel. This arrangement diminishes the wear of the parts, and promotes uniformity in their motion. If this uniformity be wanting, it is extremely difficult to set the compasses at any desired distance, for, being opened or closed by the pressure of the finger, if the joint be not good, they will move by fits and starts, and either stop short of, or go beyond

the distance required ; but, when they move evenly, the pressure may be regulated so as to open the legs to the desired extent, and the joint should be stiff enough to hold them in this position, and not to permit them to deviate from it in consequence of the small amount of pressure which is inseparable from their use. When greater accuracy in the set of the compasses is required than can be effected by the joint alone, we have recourse to the

Hair Compasses, in which the upper part of one of the steel points is formed into a bent spring, which, being fastened at one extremity to the leg of the compasses almost close up to the joint, is held at the other end by a screw. A groove is formed in the shank, which receives the spring when screwed up tight; and, by turning the screw backwards, the steel point may be gradually allowed to be pulled backwards by the spring, and may again be gradually pulled forwards by the screw being turned forwards.

Fig. 1 represents these compasses when shut; Fig. 2 represents them open, with the screw turned backwards, and the steel point *p*, in consequence moved backwards by its spring *s*, from the position represented by the dotted lines, which it would have when screwed tight up.

Fig. 3 represents a key, of which the two points fit into the two holes seen in the nut, *n*, of the joint; and by turning this nut the joint is made stiffer or easier at pleasure.

Fig. 1



Fig. 2

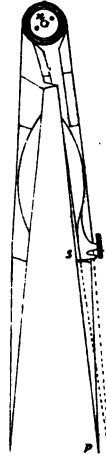


Fig. 3



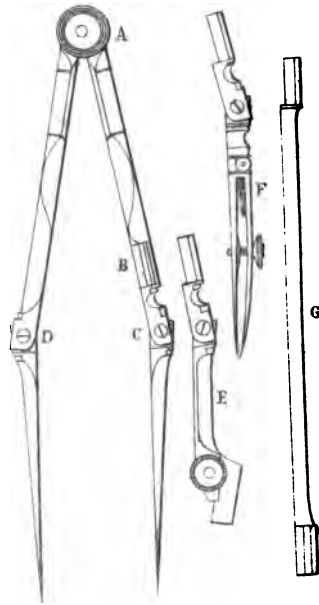
To take a Distance with the Hair Compasses.—Open them as nearly as you can to the required distance, set the fixed leg on the point from which the distance is to be taken, and make the extremity of the other leg coincide accurately with the end of the required distance, by turning the screw.

COMPASSES WITH MOVABLE POINTS.

If an arc or circle is to be described faintly, merely as a guide for the terminating points of other lines, the steel points are generally sufficient for the purpose and are susceptible of adjustment with greater accuracy than a pencil point; but in order to draw arcs or circles with ink or black-lead, compasses with a movable point are used.

In the best description of these compasses the end of the shank is formed into a strong spring, which holds firmly the movable point, or a pencil or ink point, as may be required. A lengthening bar may also be attached between the shank and the movable point, so as to strike larger circles, and measure greater distances. The movable point to be attached to the lengthening bar, as also the pen point and pencil point, are furnished with a joint that they may be set nearly perpendicular to the paper.

A, the compasses, with a movable point at B.
C and D, the joints to set each point perpendicular to the paper.
E, the pencil point.

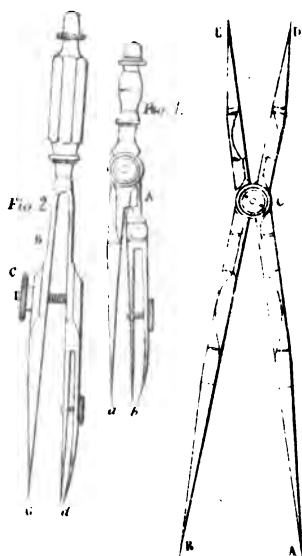


F, the pen point.

G, the lengthening bar.

To describe small arcs or circles a small pair of compasses, called *bow compasses* with a permanent ink or pencil point, are used. They are formed with a round head, which rolls with ease between the fingers. The adjoining figures present two constructions of pen bows, Fig. 1 being well adapted to describe arcs of not more than one inch radius, and Fig. 2 to describe arcs of small radii with exactness by means of the adjusting screw C.

For copying and reducing drawings, compasses of a peculiar construction are used; the simplest form of which is that called *wholes and halves*, because the longer legs being twice the length of the shorter, when the former are opened to any given line, the shorter ones will be opened to the half of that line. By their means, then, all the lines of a drawing may be reduced to one-half, or enlarged to double their length. These compasses are also useful for dividing lines by continual bisections.



PROPORTIONAL COMPASSES.

By means of this ingenious instrument, drawings may be reduced or enlarged, so that all the lines of the copy, or the areas or solids represented by its several parts, shall bear any required proportion to the lines, areas, or solids of the

original drawing. They will also serve to inscribe regular polygons in circles, and to take the square roots and cube roots of numbers. In the annexed figure the scale of lines is placed on the leg A E, on the left-hand side of the groove, and the scale of circles, on the same leg, on the right-hand side of the groove. The scales of plans and solids are on the other face of the instrument.

To set the instrument it must first be accurately closed, so that the two legs appear but as one; the nut C being then unscrewed, the slider may be moved, until the line across it coincides with any required division upon any one of the scales. Now tighten the screw, and the compasses are set.

To reduce or enlarge the Lines of a Drawing.—The line across the slider being set to one of the divisions, 2, 3, 4, &c., on the scale of lines, the points A, B, will open to double, triple, four times, &c., the distances of the points D, E*. If, then, the points A and B be opened to the lengths of the lines upon a drawing, the points D and E will prick off a copy with the lines reduced in the proportions of $\frac{1}{2}$ to 1, $\frac{1}{3}$ to 1, $\frac{1}{4}$ to 1, &c.; but, if the points D and E be opened to the lengths of the lines upon a drawing, the points A and B will prick off a copy with the lines enlarged in the proportions of 2 to 1, 3 to 1, 4 to 1, &c.

To inscribe in a Circle a regular Polygon of any Number of Sides from 6 to 20.—The line across the slider being set to any number on the scale of circles, and the points A and B being opened to the length of any radius, the points D and E will prick off a polygon of that number of sides, in the circle described with this radius; thus, if the line across the slider be set to the division marked 12 on the scale of circles, and a



* Euclid, Book vi., Prop. 4.

circle be described with the radius A B, D E will be the chord of a $\frac{1}{12}$ th part of the circumference, and will prick off a regular polygon of 12 sides in it.

To reduce or enlarge the Area of a Drawing.—The numbers upon the scale of plans are the squares of the ratios of the lengths of the opposite ends of the compasses, when the line across the slider is set to those numbers; and, the distances between the points being in the same ratio as the lengths of the corresponding ends,* the areas of the drawings, and of the several parts of the drawings, pricked off by these points, will have to one another the ratio of 1 to the number upon the scale of plans to which the instrument is set †. Thus if the line across the slider be set to 4 on the scale of plans, the distance between the points A and B will be twice as great as the distance between D and E; and, if A and B be opened out to the lengths of the several lines of a drawing, D and E will prick off a copy occupying $\frac{1}{4}$ th the area; if the line across the slides be set to 5 on the same scale, the distances between the points will be in the ratio of 1 to $\sqrt{5}$, and the area of the copy pricked off by the points D and E will be $\frac{1}{5}$ th of the area of the drawing, of which the lines are taken off by A and B: conversely, if the lines of the drawing be taken off by the points D and E, the points A and B will prick off a copy, of which the area will be 4 times or 5 times as great, according as the line across the slider is set to the division marked 4 or 5 on the scale.

To take the Square Root of a Number.—The line across the slider being set to the number upon the scale of plans, open the points A and B to take the number from any scale of equal parts, then the points D and E applied to the same scale of equal parts will take the square root of the number. Thus, to take the square root of 3, set the line across the slider to 3; open out the compasses, till A and B take off 3 from any scale

* Euclid, Book vi., Prop. 4.

† Euclid, Book vi., Props. 19, 20; and Book xii., Prop. 2.

of equal parts, and the points D and E will take off 1.73, which is the square root of 3, from the same scale of equal parts. A mean proportional between two numbers, being the square root of their product, may be found by multiplying the numbers together, and then taking the square root of the product in the manner explained above.

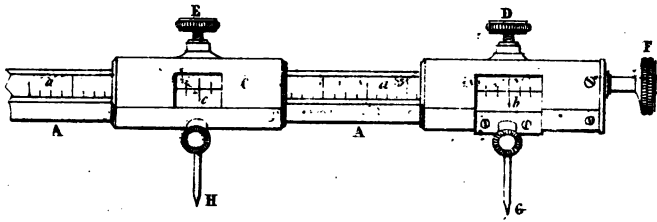
The numbers of the scale of solids are the cubes of the ratios of the lengths of the opposite ends of the compasses, when the line across the slider is set to those numbers; so that, when this line is set to the division marked 2 upon the scale of solids, the distance between the points A and B will give the side of a solid of double the content of that, of which a like side is given by the distance of the points D and E when the line is set to 3, the respective distances of the points will give the like sides of solids, the contents of which will be in the proportion of 3 to 1; and so on.

The Cube Root of a given number may be found by setting the line across the slider to the number upon the scale of solids, and, opening the points A, B, to take off the number upon any scale of equal parts, the points D, E, will then take off the required cube root from the same scale.

THE BEAM COMPASSES.

THIS instrument, consists of a beam, A, A, of any length required, generally made of well-seasoned mahogany. Upon its face is inlaid throughout its whole length a slip of holly or boxwood, *a, a*, upon which are engraved the divisions or scale, either feet and decimals, or inches and decimals, or whatever particular scale may be required.

Two brass boxes, B and C, are adapted to the beam; of which the latter may be moved, by sliding, to any part of its length, and fixed in position by tightening the clamp screw E. Connected with the brass boxes are the two points of the instrument G and H, which may be made to have any extent of opening by sliding the box C along the beam, the other box B, being firmly fixed at one extremity.



The object to be attained, in the use of this instrument, is the nice adjustment of the points G, H, to any definite distance apart. This is accomplished by two vernier or reading plates *b*, *c*, each fixed at the side of an opening in the brass boxes to which they are attached, and affording the means of minutely subdividing the principal divisions *a*, *a*, on the beam, which appear through those openings. D is a clamp screw for a similar purpose to the screw E, namely, to fix the box B, and prevent motion in the point it carries after adjustment to position. F is a slow motion screw, by which the point G may be moved any very minute quantity for perfecting the setting of the instrument, after it has been otherwise set as nearly as possible by the hand alone.

The method of setting the instrument for use may be understood from the above description of its parts, and also by the following explanation of the method of examining and correcting the adjustment of the vernier, *b*, which, like all other mechanical adjustments, will occasionally get deranged. This verification must be performed by means of a detached scale. Thus, suppose, for example, that our beam compass is divided to feet, inches, and tenths, and subdivided by the vernier to hundredths, &c. First, set the zero division of the vernier to the zero of the principal divisions on the beam, by means of the slow motion screw F. This must be done very nicely. Then slide the box C, with its point G, till the zero on the vernier *c*, exactly coincides with any principal division on the beam,

as twelve inches or six inches, &c. To enable us to do this with extreme accuracy some superior kinds of beam compasses have the box C also furnished with a tangent or slow motion screw, by which the setting of the points or divisions may be performed with the utmost precision. Lastly, apply the points to a similar detached scale, and, if the adjustment be perfect, the interval of the points, G, H, will measure on it the distance to which they were set on the beam. If they do not, by ever so small a quantity, the adjustment should be corrected by turning the screw F till the points do exactly measure that quantity on the detached scale; then, by loosening the little screws which hold the vernier *b* in its place, the position of the vernier may be gradually changed, till its zero coincides with the zero on the beam; and, then tightening the screws again, the adjustment will be complete.

In the above we have described the Beam Compass, but for all practical purposes, it is sufficient to have the beam made of well-seasoned mahogany, and to dispense with the scale and vernier. The box B, being made movable on the beam, by means of the tangent screw F, the box C, can be slid along the beam to any extent, and the points G and H, applied to a scale of equal parts and adjusted to any nicety by the screw F.

Beam Compasses made of wood, are preferable to those of brass or other metal, the latter being subject to greater expansion on account of the changes in the state of the atmosphere; they are also easily made up by any bazar carpenter.

THE DRAWING PEN.

THIS instrument is used for drawing straight lines. It consists of two blades with steel points, fixed to a handle; and they are so bent, that a sufficient cavity is left between them for the ink, when the ends of the steel points meet close together, or nearly so. The blades are set with the points more or less open by means of a mill-headed screw, so as to

draw lines of any required fineness or thickness. One of the blades is framed with a joint, so that by taking out the screw the blades may be completely opened, and the points effectively cleaned after use. The ink is to be put between the blades by a common pen; in using the pen it should be slightly inclined in the direction of the line to be drawn, and care should be taken that both points touch the paper; these observations equally apply to the pen points of the compasses before described. The drawing pen should be kept close to the straight edge, and in the same direction during the whole operation of drawing the line.

Fig. 1.



Fig. 2.

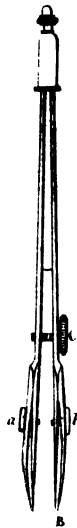


Fig. 3.



For drawing close parallel lines in mechanical and architectural drawings, or to represent canals or roads, a double pen (Fig. 2) is frequently used, with an adjusting screw to set the pen to any required small distance. This is usually called the road pen. The best pricking point is a fine needle held in a pair of forceps (Fig. 3). It is used to mark the intersections of lines, or to set off divisions from the plotting

scale and protractor. This point may also be used to prick through a drawing upon an intended copy, or, the needle being reversed, the eye end forms a good tracing point.

A STRAIGHT EDGE.

As many instruments are required to have straight edges for the purpose of measuring distances, and of drawing straight lines, it may be considered important to test the accuracy of such edges. This may be done by placing two such edges in contact and sliding them along each other, while held up between the eye and the light: if the edges fit close in some parts, so as to exclude the light, but admit it to pass between them at other parts, the edges are not true: if, however, the edges appear, as far as the test has now proceeded, to be true, still this may arise from a curvature in one edge fitting into an opposite curvature in the other; the final step then is to take a third edge, and try it in the same manner with each of the other two, and, if in each case the contact be close throughout the whole extent of the edges, then they are all three good.

“ To draw a straight line between two points upon a plane, we lay a rule so that the straight edge thereof may just pass by the two points; then, moving a fine pointed needle, or drawing pen, along this edge, we draw a line from one point to the other, which, for common purposes, is sufficiently exact; but, where great accuracy is required, it will be found extremely difficult to lay the rule equally with respect to both the points, so as not to be nearer to one point than the other. It is difficult also so to carry the needle, or pen, that it shall neither incline more to one side than the other of the rule; and thirdly, it is very difficult to find a rule that shall be perfectly straight.

“ If the two points be very far distant, it is almost impossible to draw the line with accuracy and exactness; a circular line may be described more easily, and more exactly, than a straight or any other line, though even then

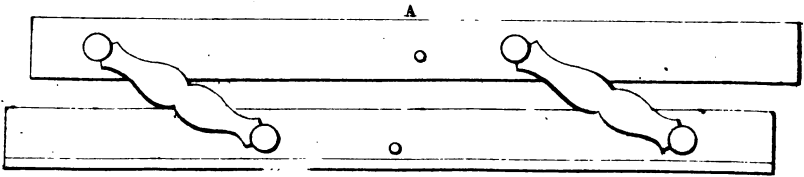
many difficulties occur, when the circle is required to be of a large radius.

“ And let no one consider these reflections as the effect of too scrupulous exactness, or as an unnecessary aim at precision; for, as the foundation of all our knowledge in geography, navigation, and astronomy, is built on observations, and all observations are made with instruments, it follows that the truth of the observations, and the accuracy of the deductions therefrom, will principally depend on the exactness with which the instruments are made and divided, and that those sciences will advance in proportion as these are less difficult in their use, and more perfect in the performance of their respective operations.”

OF PARALLEL RULES.

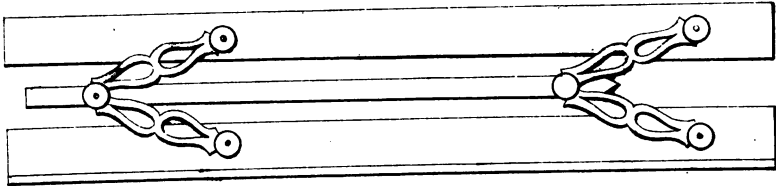
Parallel lines occur so continually in every species of mathematical drawing, that it is no wonder so many instruments have been contrived to delineate them with more expedition than could be effected by the general geometrical methods: of the various contrivances for this purpose, the following are those most approved,

The Common Parallel Rule.—This consists of two straight rules, which are connected together, and always maintained in a parallel position by the two equal and parallel bars, which move very freely on their centres, or rivets, by which they are fastened to the rules.

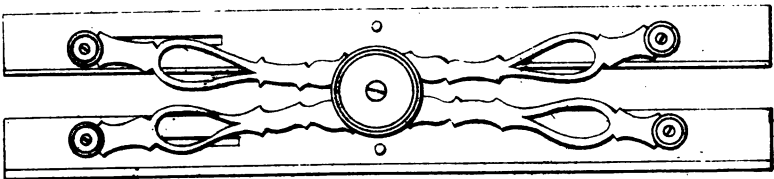


The Double Parallel Rule.—This instrument is constructed exactly upon the same principles as the foregoing, but with this advantage, that in using it, the movable rule may always

be so placed, that its ends may be exactly over, or even with the ends of the fixed rule, whereas in the former kind, they are always shifting away from the ends of the fixed rule; it consists of two equal flat rules, and a middle piece; they are connected together by four brass bars, the ends of two bars are rivetted on the middle line of one of the straight rules; the ends of the other two bars are rivetted on the middle line of the other straight rule; the other ends of the brass bars are taken two and two, and rivetted on the middle piece, as is evident from the figure. It would be needless to observe, that the brass bars move freely on their rivets, as so many centres.



The Cross-barred Parallel Rule.—In this, two straight rules are joined by two brass bars, which cross each other, and turn on their intersection as on a centre; one end of each bar moves on a centre, the other slides in a groove, as the rules recede from each other.

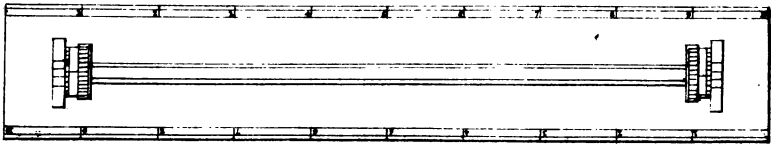


As the three parallel rules above described are all used in the same way, one problem will serve for them all.

A right line being given, to draw a line parallel thereto by either of the foregoing instruments :

Set the edge of the uppermost rule to the given line ; press the edge of the lower rule tight to the paper with one hand, and with the other move the upper rule, till its edge coincides with the given point ; and a line drawn along the edge through the point is the line required.

The Rolling Parallel Rule, is a rectangular parallelogram of black ebony or brass. It is supported by two small wheels, which are connected together by a long axis, the wheels being exactly of the same size, and their rolling surfaces being parallel to the axis. When they are rolled backwards or forwards, the axis and rule will move in a direction parallel to themselves.



The wheels are somewhat indented, to prevent their sliding on the paper. In rolling these rules one hand only must be used, and the fingers should be placed nearly in the middle of the rule that one end may not have a tendency to move faster than the other. The wheels only should touch the paper when the rule is moving, and the surface of the paper should be smooth and flat. This rule is sometimes made with slips of ivory laid on the edges and divided into inches and tenths.

CHAPTER VIII.

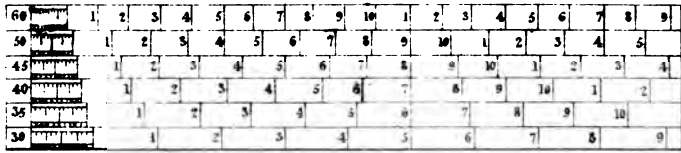


ON SCALES.

SCALES of equal parts are used for measuring straight lines, and laying down distances, each part answering for one foot, one yard, one chain, &c., as may be convenient, and the plan will be larger or smaller as the scale contains a smaller or a greater number of parts in an inch.

Scales of equal parts may be divided into three kinds; simply divided scales, diagonal scales, and vernier scales.

Simply divided Scales.—Simply divided scales consist of any extent of equal divisions, which are numbered 1, 2, 3, &c., beginning from the second division on the left hand. The first of these primary divisions is subdivided into ten equal parts, and from these last divisions the scale is named. Thus it is called a scale of 30, when 30 of these small parts are equal to one inch. If, then, these subdivisions be taken as units, each to represent one mile, for instance, or one chain, or one foot, &c., the primary divisions will be so many tens of miles, or of chains, or of feet, &c.; if the subdivisions are taken as tens, the primary divisions will be hundreds; and, if the primary divisions be units, the subdivisions will be tenths.



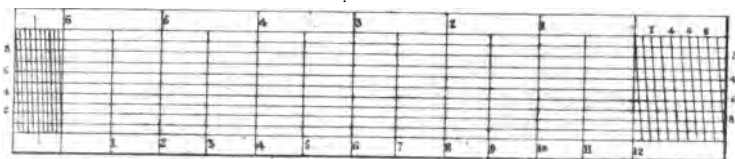
The above diagram represents six of the simply divided scales, which are generally placed upon the plain scale. To adapt them to feet and inches, the first primary division is divided duodecimally upon an upper line. To lay down 360, or 36, or 3.6, &c., from any one of these scales, extend the compasses from the primary division numbered 3 to the 6th lower subdivision, reckoning backwards, or towards the left hand. To take off any number of feet and inches, 6 feet 7 inches for instance, extend the compasses from the primary division numbered 6, to the 7th upper subdivision, reckoning backwards, as before.

Diagonal Scales.—In the simply divided scales one of the primary divisions is subdivided only into ten equal parts, and the parts of any distance which are less than tenths of a primary division cannot be accurately taken off from them; but, by means of a diagonal scale, the parts of any distance which are the hundredths of the primary divisions are correctly indicated, as will easily be understood from its construction, which we proceed to describe.

Draw eleven parallel equidistant lines; divide the upper of these lines into equal parts of the intended length of the primary divisions; and through each of these divisions draw perpendicular lines, cutting all the eleven parallels, and number these primary divisions, 1, 2, 3, &c., beginning from the second.

Subdivide the first of these primary divisions into ten equal parts, both upon the highest and lowest of the eleven parallel lines, and let these subdivisions be reckoned in the opposite direction to the primary divisions, as in the simply divided scales.

Draw the diagonal lines from the tenth subdivision below to the ninth above. From the ninth below to the eighth above, and so on, till we come to a line from the first below to the zero point above. Then, since these diagonal lines are all parallel, and consequently every where equidistant, the distance between any two of them in succession, measured upon any of the eleven parallel lines which they intersect, is the same as this distance measured upon the highest or lowest of these lines, that is, as one of the subdivisions before mentioned. But the distance between the perpendicular, which passes through the zero point, and the diagonal through the same point, being nothing on the highest line, and equal to one of the subdivisions on the lowest line, is equal* to one-tenth of a subdivision on the second line, to two-tenths of a subdivision on the third, and so on; so that this, and consequently each of the other diagonal lines, as it reaches each successive parallel, separates further from the perpendicular through the zero point by one-tenth of the extent of a subdivision, or one-hundredth of the extent of a primary division.



The above figure represents the two diagonal scales which are usually placed upon the plain scale of six inches in length. In one, the distances between the primary divisions are each half an inch, and in the other a quarter of an inch. The parallel next to the figures numbering these divisions must be considered the highest or first parallel in each of these scales to accord with the above description.

The primary divisions being taken for units, to set off the numbers 5.74 by the diagonal scale. Set one foot of the

* Euclid. Book vi., Prop. 4.

compasses on the point where the fifth parallel cuts the eighth diagonal line, and extend the other foot to the point where the same parallel cuts the fifth vertical line.

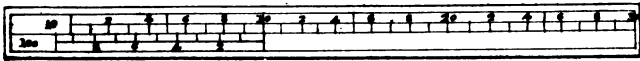
The primary divisions being reckoned as tens, to take off the number 46.7. Extend the compasses from the point where the eighth parallel cuts the seventh diagonal to the point where it cuts the fourth vertical.

The primary divisions being hundreds, to take off the number 253. Extend the compasses from the point where the fourth parallel cuts the sixth diagonal to the point where it cuts the second vertical.

Now, since the first of the parallels, of the diagonals, and of the verticals indicate the zero points of the third, second, and first figures respectively, the second of each of them stands for, and is marked, 1, the third, 2, and so on, and we have the following general rule:

To take off any number to three places of figures upon a Diagonal Scale.—On the parallel indicated by the third figure, measure from the diagonal indicated by the second figure to the vertical indicated by the first.

Vernier Scales.—The nature of these scales will be understood from their construction. To construct a vernier scale, which shall enable us to take off a number to three places of figures, divide all the primary divisions into tenths, and number these subdivisions, 1, 2, 3, &c., from the left hand towards the right throughout the whole extent of the scale.



Take off now, with the compasses, eleven of these subdivisions, set the extent off backwards from the end of the first primary division, and it will reach beyond the beginning of this division, or zero point, a distance equal to one of the subdivisions. Now divide the extent thus set off into ten equal

parts, marking the divisions on the opposite side of the divided line to the strokes marking the primary divisions and the subdivisions, and number them 1, 2, 3, &c., backwards from right to left. Then, since the extent of eleven subdivisions has been divided into ten equal parts, so that these ten parts exceed by one subdivision the extent of ten subdivisions, each one of these equal parts, or, as it may be called, one division of the vernier scale, exceeds one of the subdivisions by a tenth part of a subdivision, or a hundredth part of a primary division. In our figure the distances between the primary divisions are each one inch, and, consequently, the distances between the subdivisions are each one-tenth of an inch, and the distance between the divisions of the vernier scale each one-tenth and one-hundredth of an inch.

To take off the number 253 from this scale. Increase the first figure 2 by 1, making it 3; because the vernier scale commences at the end of the first primary division, and the primary divisions are measured from this point and not from the zero point.* The first thus increased with the second now represents 35 of the subdivisions from the zero point, from which the third figure, 3, must be subtracted, leaving 32; since three divisions of the vernier scale will contain three of these subdivisions, together with three-tenths of a subdivision. Place then, one point of the compasses upon the third division of the vernier scale, and extend the other point to the 32nd subdivision, or the second division beyond the 3rd primary division, and, laying down the distance between the points of the compass, it will represent 253, or 25.3, or 2.53, according as the primary divisions are taken as hundreds, tens, or units.

General Rule.—To take off any number to three places of figures upon this vernier scale. Increase the first figure by one, subtract the third figure from the second, borrowing one from the first increased figure, if necessary, and extend the

* If the vernier scale were placed to the left of the zero point, a distance less than one primary division could not always be found upon the scale.

compasses from the division upon the vernier scale, indicated by the third figure to the subdivision indicated by the number remaining after performing the above subtraction.

Suppose it were required to take off the number 253.5. By extending the compasses from the third division of the vernier scale to the 32nd subdivision, the number 253 is taken off, as we have seen. To take off, therefore, 253.5, the compasses must be extended from one of these points to a short distance beyond the other. Again, by extending the compasses from the 4th division of the vernier scale to the 31st subdivision, the number 254 would be taken off. To take off 253.5, then the compasses must be extended from one of these points to within a short distance of the other; and, by setting the compasses so that, when one point of the compasses is set successively on the 3rd and 4th division of the vernier scale, the other point reaches as far beyond the 32nd subdivision as it falls short of the 31st, the number 253.5 is taken off. If the excess in one case be twice as great as the defect in the other, the distance represents the number $253\frac{2}{3}$, or 253.66; and if the excess be half the defect, the distance represents $253\frac{1}{3}$, or 253.33. Thus distances may be set off with an accurately constructed scale of this kind to within the three-hundredth part of a primary division, unless these divisions be themselves very small.

We are not aware that a scale of this kind has been put upon the plain scales sold by any of the instrument makers; but, during the time occupied in plotting an extensive survey, the paper which receives the work is affected by the changes which take place in the hygrometrical state of the air, and the parts laid down from the same scale, at different times, will not exactly correspond, unless this scale has been first laid down upon the paper itself, and all the divisions have been taken from the scales so laid down, which is always in the same state of expansion as the plot. For plotting, then, an extensive survey, and accurately filling in the minutæ, a diagonal, or

vernier scale may advantageously be laid down upon the paper upon which the plot is to be made. A vernier scale is preferable to a diagonal scale, because in the latter it is extremely difficult to draw the diagonals with accuracy, and we have no check upon its errors; while in the former the uniform manner in which the strokes of one scale separate from those of the other is some evidence of the truth of both.

ON THE PROTRACTING SCALES.

THE nature of these scales will be understood from the following construction. (Plate II. Fig. 1.)

With centre O, and radius OA, describe the circle ABCD; and through the centre O draw the diameters AC, and BD, at right angles to each other, which will divide the circle into four quadrants, AB, BC, CD, and DA.

Divide the quadrant CD into nine equal parts, each of which will contain ten degrees, and these parts may again be subdivided into degrees, and, if the circle be sufficiently large, into minutes.

Set one foot of the compasses upon C, and transfer the divisions in the quadrant CD to the right line CD, and we shall have a scale of Chords.*

From the divisions in the quadrant CD, draw right lines parallel to DO, to cut the radius OC, and, numbering the divisions from O, towards C, we shall have a scale of Sines.

If the same divisions be numbered from C, and continued to A, we shall have a scale of versed sines.

* We give the constructions in the text to show the nature of the scales; but in practice, a scale of chords is most accurately constructed by values computed from tabulated arithmetical values of sines, which computed values are set off from a scale of equal parts; and the circle is divided most accurately by means of such computed chords. The limits of this work forbid our entering further upon this interesting subject. All the other scales will also be most accurately constructed from computed arithmetical values, taken off by means of the beam compasses hereafter described, and corrected by the aid of a good Bird's vernier scale.

From the centre O, draw right lines through the divisions of the quadrant CD, to meet the line CT, touching the circle at C, and, numbering from C, towards T, we shall have a scale of Tangents.

Set one foot of the compasses upon the centre O, and transfer the divisions in CT into the right line OS, and we shall have a scale of Secants.

Right lines, drawn from A to the several divisions in the quadrant CD, will divide the radius OD into a line of Semi-tangents, or tangents of half the angles indicated by the numbers; and the scale may be continued by continuing the divisions from the quadrant CD, through the quadrant DA, and drawing right lines from A, through these divisions to meet the radius OD, produced.

Divide the quadrant AD into eight equal parts, subdivide each of these into four equal parts, and, setting one foot of the compasses upon A, transfer these divisions to the right line AD, and we shall have a scale of Rhumbs.

Divide the radius AO into 60 equal parts, and number them from O towards A; through these divisions draw right lines parallel to the radius OB, to meet the quadrant AB; and, with one foot of the compasses upon A, transfer these divisions from the quadrant to the right line AB, and we shall have a scale of Longitudes.

Place the chord of 60° , or radius,* between the radii OC and OB, meeting them at equal distances from the centre; divide the quadrant CB into six equal parts, for intervals of hours, subdividing each of these parts into 12 for intervals of 5 minutes, and further subdividing for single minutes if the circle be large enough; and from the centre O, draw right lines to the divisions and subdivisions of the quadrant, intersecting the chord or radius placed in the quadrant; and we shall have a scale of Hours.

* Chord of 60° is equal to radius. Part I. Chap. 2, Theor. 14.

Prolong the touching line TC to L; set off the scale of sines from C to L; draw right lines from the centre O to the divisions upon CL, and from the intersections of these lines with the quadrant CB draw right lines parallel to the radius OC, to meet the radius OB, and we shall have a scale of Latitudes.*

Corresponding lines of hours and latitudes may also be constructed (as represented in our figure) more simply, and on a scale twice as large as by the preceding method, as follows:

With the chord of 45° set off from B to E, and again from B to F, we obtain a quadrant EF bisected in B; and, the chord of 60° or radius being set off from A, C, F, and E, this quadrant is divided into six equal parts. From the centre O, draw straight lines through these divisions to meet the line touching the circle at B, and we shall have the line of Hours.

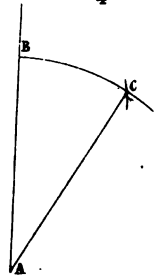
From the point D, draw right lines through the divisions upon the line of sines OC, to meet the circumference BC, and transferring these divisions from B, as a centre to the chord BC, we shall have the corresponding line of Latitudes.

It is not necessary that these scales should all be projected to the same radius; but those which are used together, as the rhumbs and chords, the chords and longitudes, the sines, tangents, secants, and semi-tangents, and, lastly, the hours and latitudes, must be so constructed necessarily. In the diagram (Plate II. Fig. 2) we have laid down the hours and latitudes to a radius equal to the whole length of the scale, the other lines being laid down to the radius used in the foregoing construction.

* The line of latitudes is a line of sines, to radius equal the whole length of the line of hours, of the angles, of which the tangents are equal to the sines of the latitudes. The middle of the hour line being numbered for three o'clock, the divisions for the other hours are found by setting off both ways from the middle the tangents of $n. 15^\circ$, $n.$ being the number of hours from three o'clock, that is, one for two o'clock, and four o'clock, two for one o'clock and five o'clock, and three for twelve o'clock and six o'clock.

The Line of Chords is used to set off an angle, or to measure an angle already laid down. (Page 29, 30.)

The Line of Rhumbs is a scale of the chords of the angles of deviation from the meridian denoted by the several points and quarter points of the compass, enabling the navigator, without computation, to lay down or measure a ship's course upon a chart. Thus, supposing the ship's course to be N.N.E. $\frac{3}{4}$ E. Through the point A, representing the ship's place upon the chart, draw the meridian AB, and with centre A and distance equal to the extent of 60° upon the line of chords, describe an arc cutting AB in B; then on the line of rhumbs take the extent to the third subdivision beyond the division marked 2, because N.N.E. is the second point of the compass from the north, and with one foot of the compasses on B describe an arc intersecting BC in C: join AC, and the angle BAC will represent the ship's course. On the other hand, if a ship is to be sailed from the point A to a point on the line AC on a chart, draw the meridian AB, describe an arc BC with radius equal to the chord of 60° , as before, and the extent from B to C, applied to the line of rhumbs, will give 2 Pts. 3 Qrs., denoting that the ship must be sailed by the compass N.N.E. $\frac{3}{4}$ E.



The Line of Longitudes shows the number of equatorial miles in a degree of longitude on the parallels of latitude indicated by the degrees on the corresponding points of the line of chords.

Example.—A ship in latitude 60° N. sailing E. 79 miles, required the difference of longitude between the beginning and end of her course. Opposite 60 on the line of chord stands 30 on the line of longitudes, which is, therefore, the number of equatorial miles in a degree of longitude at that latitude.

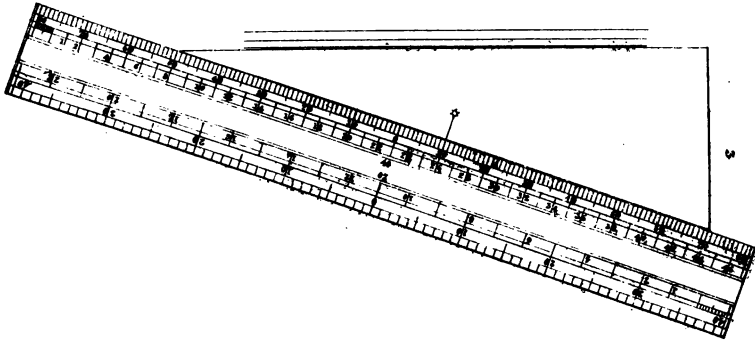
Hence, as $30 : 79 :: 60 : 158$ miles, the required difference of longitude.

The Lines of Sines, Secants, Tangents, and Semi-tangents are principally used for the several projections, or perspective

representations, of the circles of the sphere, by means of which maps are constructed. Thus, the meridians and parallels of latitude being projected, the countries intended to be represented are traced out according to their respective situations and extent, the position of every point being determined by the intersection of its given meridian and parallel of latitude.

MARQUOIS' SCALES.

THESE scales consists of a right-angle triangle, of which the hypotenuse or longest side is three times the length of the shortest, and two rectangular rules. The accompanying diagram represents the triangle and one of the rules, as being used to draw



a series of parallel lines. Either rule is one foot long, and has, parallel to each of its edges, two scales, one placed close to the edge and the other immediately within this, the outer being termed the artificial, and the inner, the natural scale. The divisions upon the outer scale are three times the length of those upon the inner scale, so as to bear the same proportion to each other that the longest side of the triangle bears to the shortest. Each inner, or natural scale, is, in fact, a simply divided scale of equal parts having the primary divisions numbered from the left hand to the right throughout the whole extent of the rule. The first primary division on the left hand is subdivided into ten equal parts, and the number of these subdivisions in an inch is marked underneath the scale, and

gives it its name. On one of the pair of Marquois' scales now before us, we have, on one face, scales of 30 and 60, on the obverse, scales of 25 and 50, and on the other we have on one face scales of 35 and 45, and on the obverse, scales of 20 and 40. In the artificial scales the zero point is placed in the middle of the edge of the rule, and the primary divisions are numbered both ways from this point to the two ends of the rule, and are every one, subdivided into ten equal parts, each of which is, consequently, three times the length of a subdivision of the corresponding natural scale.

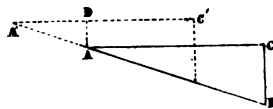
The triangle has a short line drawn perpendicular to the hypotenuse near the middle of it, to serve as an index or pointer; and the longest of the other two sides has a sloped edge.

To draw a Line parallel to a given Line, at a given Distance from it. 1st. Having applied the given distance to the one of the natural scales which is found to measure it most conveniently, place the triangle with its sloped edge coincident with the given line, or rather at such small distance from it, that the pen or pencil passes directly over it when drawn along this edge. 2nd. Set the rule closely against the hypotenuse, making the zero point of the corresponding artificial scale coincide with the index upon the triangle. 3rd. Move the triangle along the rule, to the left or right, according as the required line is to be above or below the given line, until the index coincides with the division or subdivision corresponding to the number of divisions or subdivisions of the natural scale, which measures the given distance; and the line drawn along the sloped edge in its new position will be the line required.*

* If ABC represent the triangle in its new position, and the dotted lines represent its original position, we have,
by similar triangles, ABC, A'AD,

$$\begin{aligned} AD : AA' &:: BC : BA \\ &:: 1 : 3; \end{aligned}$$

and therefore AD contains as many divisions of the natural as AA' contains of the artificial scale.



Note.—The natural scale may be used advantageously in setting off the distances in a drawing, and the corresponding artificial scale in drawing parallels at required distances.

To draw a Line perpendicular to a given Line from a given point in it. 1st. Make the shortest side of the triangle coincide with the given line, and apply the rule closely against the hypotenuse. 2nd. Slide the triangle along the rule until a line drawn along the sloped edge passes through the given point; and the line so drawn will be the line required.

The advantages of Marquois' scales are: 1st, that the sight is greatly assisted by the divisions on the artificial scale being so much larger than those of the natural scale to which the drawing is constructed: 2nd, that any error in the setting of the index produces an error of but one-third the amount in the drawing.

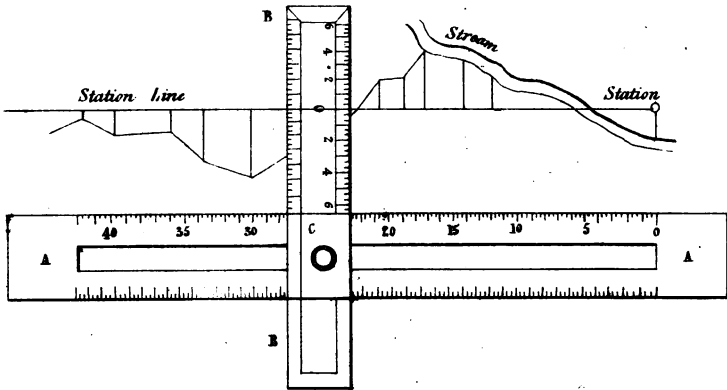
If the triangle be accurately constructed, these scales may be advantageously used for dividing lines with accuracy and despatch.

PLOTTING SCALES.

PLOTTING scales, also called feather-edge scales, are straight rules, usually about ten or twelve inches long. Each rule has scales of equal parts, decimally divided, placed upon its edges, which are made sloping, so that the extremities of the strokes marking the divisions lie close to the paper. The primary divisions represent chains and the subdivisions, consequently, ten links each, as there are 100 links on the surveying chain. Plotting scales may be procured in sets, each with a different number of chains to the inch.

The advantages of this arrangement are, that the distances required can be transferred with great expedition from the scale to the paper by the aid of the pricking point alone, and the marks denoting the divisions are in no danger of becoming defaced, as upon the plain scale, by the frequent application of the compasses.

For plotting offsets, measured to the right and left of station lines, ivory or brass scales with fiducial edges may be employed.



The above diagram represents an ingenious contrivance for an offset scale; the graduated scale, A, A, is perforated nearly its whole length by a dovetail-shaped groove, for the reception of a sliding piece which is fastened to the cross scale, B, B, by the screw, C. It will readily be understood from an inspection of the figure, that the cross scale, B, slides along the scale, A, the whole length of the groove, and at right angles to it. The graduations on both the scales represent either feet or links, &c., or whatever length may have been assumed as the unit in the operation of measuring. The mode of its application is simply this: place the scale, A, A, on the paper, parallel to the line on which the offsets are to be plotted, and at such a distance, that the zero division on the cross scale, B, (which is placed about its middle) may coincide with it as the scale slides along, and also that the zero of the scale, A, may be exactly opposite that end of the line at which the measurement commenced; then, in sliding the scale, B, from the beginning of the line, stop it at every divisional line on A, corresponding to the distance on the station line at which an

off-set was taken, and lay off the exact length of the off-set from the edge of the scale, B, either to the right or left of the station line, to which it will be at right angles as taken in the field; the instrument thus gives both dimensions at the same time. It is perhaps needless to add, that the extremities of the off-sets being connected, will represent the curved line, &c. to which they were measured; weights may be placed at the two ends of the scale, A, A, to keep it steadily in its position. In our figure, the instrument is represented as in the act of plotting off-sets upon a station line.

It may be useful here to add a few remarks on the scales used in plotting a survey.

One Chain to an inch (80 inches to 1 mile) is perhaps the largest scale used in plans of land and road surveys, and is adopted only where great clearness is required, and when the work is of limited extent. It is a very useful scale for plans of building or pleasure grounds.

Two Chains to an inch (40 inches to 1 mile) is a very clear scale for land surveys, the extent of which is not very great. It may likewise be used with advantage for gardens and building grounds.

Three Chains to an inch ($26\frac{2}{3}$ inches to 1 mile) has hitherto not been in very general use, it is, however, the smallest scale that can with safety be used in all cases for plans, from which the contents are to be computed.

Four Chains to an inch (20 inches to 1 mile) is a scale frequently employed in plotting surveys of estates, and is very convenient for either enlargement or reduction.

Smaller scales are usually employed in extensive operations: 6 inches to 1 mile is a large scale for the survey of a district, 4 inches to 1 mile is the scale used on the Revenue surveys for Village maps; 1 inch to 1 mile for Pergunnah maps, and in the Revenue Surveyor General's Office, in the compilation of the Geographical maps, 4 miles to 1 inch is made use of.

CHAPTER IX.

INSTRUMENTS FOR PLOTTING A SURVEY.

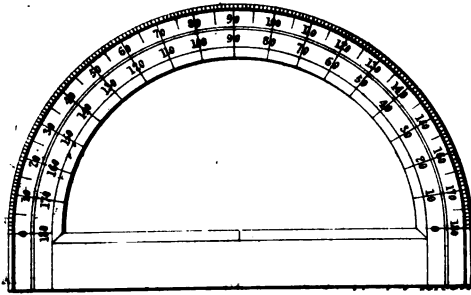
IN plotting a Survey, as in taking it, due regard must be had to both accuracy and despatch, and we should aim to lay down the various points observed with an accuracy proportionate to the accuracy of the survey itself. For this purpose certain instruments are used, a short description of which we will here give.

OF THE PROTRACTOR.

THIS is an instrument used to protract, or lay down an angle containing any number of degrees, or to find how many degrees are contained in any given angle. There are two kinds put into cases of mathematical drawing instruments, one in the form of a semicircle, the other in the form of a parallelogram. The circle is undoubtedly the only natural measure of angles; when a straight line is therefore used, the divisions thereon are derived from a circle, or its properties, and the straight line is made use of for some relative convenience: it is thus the parallelogram is often used as a protractor, instead of the semicircle, because it is in some cases more convenient, and that other scales, &c., may be placed upon it.

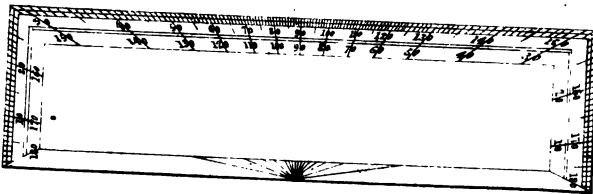
THE SEMICIRCULAR PROTRACTOR.

THIS instrument is divided into 180 equal parts or degrees which are numbered at every tenth degree each way, for the convenience of reckoning either from the right towards the left or from the left towards the right; or the more easily to lay down an angle from either end of the line, beginning at each end with 10, 20, &c., and proceeding to 180 degrees. The edge is the diameter of the semicircle, and the mark in the middle points out the centre.



THE RECTANGULAR PROTRACTOR.

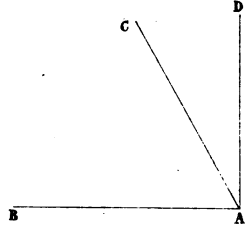
THE divisions are here as in the semicircular one numbered both ways; the blank side represents the diameter of a circle. The side of the protractor to be applied to the paper is made flat, and that whereon the degrees are marked, is chamfered or sloped away to the edge, that an angle may be more easily measured, and the divisions set off with greater exactness.



APPLICATION OF THE PROTRACTOR TO USE.

A number of degrees being given, to protract, or lay down an angle whose measure shall be equal thereto.

To lay down an angle of 60 degrees from the point A of any line AB, apply the diameter of the protractor to the line AB, so that the centre thereof may coincide exactly with the point A; then with a protracting pin make a fine dot at C against 60 upon the limb of the protractor, now remove the protractor and draw a line from A through the point C, and the angle CAB, contains the given number of degrees.



To find the number of degrees contained in a given angle BAC.

Place the centre of the protractor upon the angular point A, and the fiducial edge, or diameter, exactly upon the line AB; then the degree upon the limb that is cut by the line CA, will be the measure of the given angle, which, in the present instance, is found to be 60 degrees.

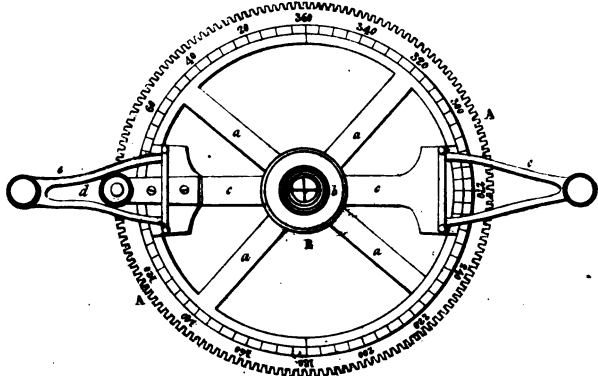
From a given point A, in the line AB, to erect a perpendicular to that line.

Apply the protractor to the line AB, so that the centre may coincide with the point A, and the division marked 90 may be cut by the line AB, then a line DA drawn against the diameter of the protractor will be perpendicular to AB.

 THE CIRCULAR PROTRACTOR.

THE circular protractor is a complete circle, A, A, connected with its centre by four radii a, a, a, a . The centre is left open,

and surrounded by a concentric ring, or collar, *b*, which carries two radial bars, *c*, *c*. To the extremity of one bar is a pinion *d*, working in a toothed rack quite round the outer circumference of the protractor. To the opposite extremity of the other bar, *c*, is fixed a vernier, which subdivides the primary



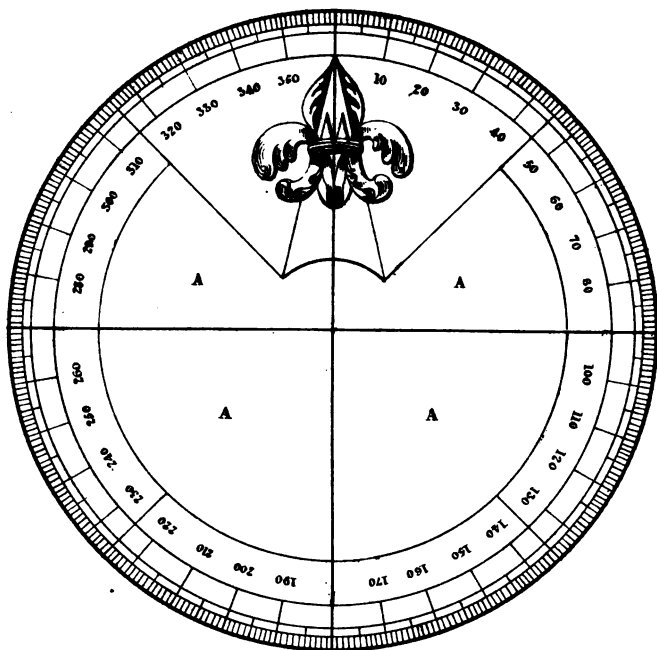
divisions on the protractor to single minutes, and by estimation to 30 seconds. This vernier, as may readily be understood from the engraving, is carried round the protractor by turning the pinion *d*. Upon each radial bar, *c*, *c*, is placed a branch *e*, *e*, carrying at their extremities a fine steel pricker whose points are kept above the surface of the paper by springs placed under their supports, which give way when the branches are pressed downwards, and allow the points to make the necessary punctures in the paper. The branches *e*, *e* are attached to the bars *c*, *c*, with a joint which admits of their being folded backwards over the instrument when not in use, and for packing in its case. The centre of the instrument is represented by the intersection of two lines drawn at right angles to each other on a piece of plate glass, which enables the person using it to place it so that the centre, or intersection of the cross-lines, may coincide with any given point on

the plan. If the instrument is in correct order, a line connecting the fine pricking points with each other would pass through the centre of the instrument, as denoted by the before-mentioned intersection of the cross-lines upon the glass, which it may be observed, are drawn so nearly level with the under surface of the instrument as to do away with any serious amount of parallax, when setting the instrument over a point from which any angular lines are intended to be drawn.

In using this instrument the vernier should first be set to zero (or the division marked 360) on the divided limb and then placed on the paper, so that the two fine steel points may be on the given line (from whence other and angular lines are to be drawn), and the centre of the instrument coincide with the given angular point on such line. This done, press the protractor gently down, which will fix it in position by means of very fine points on the under side. It is now ready to lay off the given angle, or any number of angles that may be required, which is done by turning the pinion *d* till the opposite vernier reads the required angle. Then press downwards the branches *e, e* which will cause the points to make punctures in the paper at opposite sides of the circle; which being afterwards connected, the line will pass through the given angular point, if the instrument was first correctly set. In this manner, at one setting of the instrument, a great number of angles, or a complete circular protractor, may be laid off from the same point.

THE CIRCULAR "TALC" PROTRACTOR.

A VERY serviceable protractor can be made in the following manner, especially for field-work :



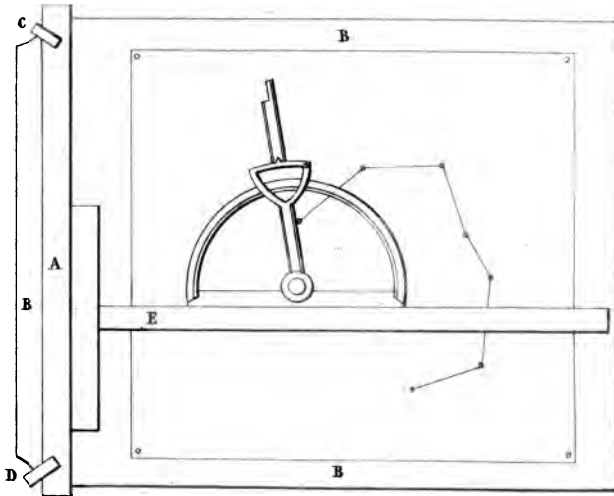
Draw on a piece of paper, a protractor, as in the above figure, and of the same size; cut out the circle and the part marked A, and stick the remainder with a little clean paste between two thin pieces of talc;* when dry, cut the talc with a pair of scizzors, to the shape of the exterior circle. Before sticking on the upper piece of talc, draw, on the lower piece by scratching, with a needle or point of a pricker, the North and South, and East and West lines, intersecting one another in the centre; rub these two lines over with a mixture of black lead and oil which will leave an indelible mark, and which cannot be effaced, being protected by the upper piece of talc.

* We strongly recommend to the notice of all Surveyors the mineral substance called "Talc" it is procurable in nearly every Bazar in India, and is most useful, generally, where cleanliness is an object, for sticking at the bottom of scales, rules, weights, and indeed anything that has to be moved about the surface of paper or maps of any kind.

The most economical and the least troublesome way of preparing the above protractors, is to draw one very carefully on a piece of paper, and get it lithographed; two or three rupees would pay for striking off a hundred, and including the price of as much talc as would be sufficient to cover them all, they would cost the Surveyor about one anna each, and be a ten year's supply to him.

THE T SQUARE AND SEMICIRCULAR PROTRACTOR.

WE cannot speak too highly of a method by which a survey



can be most expeditiously as well as accurately plotted, by means of the T square and semicircular protractor, the manner of using which is thus described by Mr. Howlett,* in vol. i. of Papers on Subjects connected with the Duties of the Royal Engineers:—

“As, when away from home, it seldom happens that the surveyor can obtain a good drawing board, or even a table with a good straight edge, I fix a flat ruler, A, to the table B, B, B, by means of a pair of clamps, C, D, and against this ruler I work the pattern square E, one side of which has the stock

* Chief draughtsman, Royal Ordnance Office.

flush with the blade; or, if a straight-edged board be at hand, then the square may be turned over, and used against that edge instead of the ruler A. Here, then, is the most perfect kind of parallel ruler that art can produce, capable of carrying the protractor over the whole of a sheet of plotting paper of any size, and may be used upon a table of any form. It is convenient to suppose the north on the left hand, and the upper edge of the blade to represent the meridian of the station.

“ This protractor is held in the hand while the vernier is set, which is an immense comfort to the sight; and it will be seen that, as both sides of the arm are parallel with the zero and centre, the angle may be drawn on the paper against either side, as the light or other circumstances may render desirable.”

From this description and a mere glance at the plate, it is clear that angles taken with the theodolite can be transferred to the plot as accurately as the protractor can be set; namely, to a single minute, and that, too, in a rapid and pleasant manner.

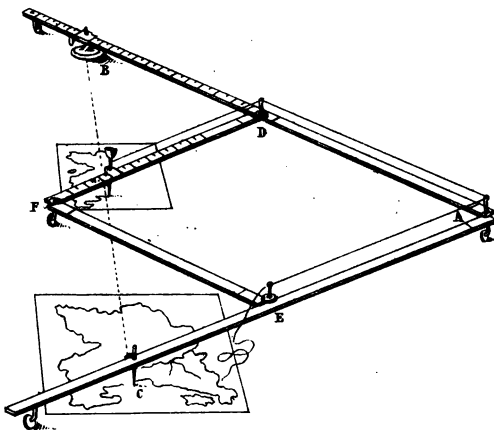
These drawing boards and T squares are in use in some of the Revenue Surveys, they are well adapted for Natives, and more particularly for such as are unable to understand the correct method of keeping a Field Book. The T rule however is generally made to slide along the edge of the drawing board, the rule having a projecting shoulder for the purpose. The method of using them, with the circular protractor, will hereafter be more particularly noticed.

THE PENTAGRAPH.

THE Pentagraph consists of four rulers, AB, AC, DF, and EF, made of stout brass. The two longer rulers, AB, and AC, are connected together by, and have a motion round a centre at A. The two shorter rulers are connected in like manner with each other at F, and with the longer rulers at D and E, and, being equal in length to the portions AD and AE of the longer rulers, form with them an accurate parallelogram, ADFE, in every position of the instrument. Several ivory castors support the instrument, parallel to the paper, and allow it to move freely over it in all directions. The arms, AB and

DF, are graduated and marked $\frac{1}{3}$, $\frac{2}{3}$, &c., and have each a sliding index, which can be fixed at any of the divisions by a milled-headed clamping screw, seen in the engraving. The sliding indices have each of them a tube, adapted either to slide on a pin rising from a heavy circular weight called the fulcrum, or to receive a sliding holder with a pencil or pen, or a blunt tracing point, as may be required.

When the instrument is correctly set, the tracing point, pencil, and fulcrum will be in one straight line, as shown by the dotted line in the figure. The motions of the tracing point and pencil are then, each compounded of two circular motions, one about the fulcrum, and the other about the joints at the ends of the rulers upon which they are respectively placed. The radii of these motions form sides about equal angles of two similar triangles, of which the straight line BC, passing through the tracing point, pencil, and fulcrum, forms the third sides. The distances passed over by the tracing point and pencil, in consequence of either of these motions, have then the same ratio, and, therefore, the distances passed over in consequence of the combination of the two motions have also the same ratio, which is that indicated by the setting of the instrument.



Our diagram represents the pentagraph in the act of reducing a plan to a scale of half the original. For this purpose the sliding indices are first clamped at the divisions upon the arms marked $\frac{1}{2}$; the tracing point is then fixed in a socket at C, over the original drawing; the pencil is next placed in the tube of the sliding index upon the ruler DF, over the paper to receive the copy; and the fulcrum is fixed to that at B, upon the ruler AB. The instrument being now ready for use, if the tracing point at C be passed delicately and steadily over every line of the plan, a true copy, but of one-half the scale of the original, will be marked by the pencil on the paper beneath it. The fine thread represented as passing from the pencil quite round the instrument to the tracing point at C, enables the draughtsman at the tracing point to raise the pencil from the paper, whilst he passes the tracer from one part of the original to another, and thus to prevent false lines from being made on the copy. The pencil holder is surmounted by a cup, into which sand or shot may be put, to press the pencil more heavily on the paper, when found necessary.

If the object were to enlarge the drawing to double its scale, then the tracer must be placed upon the arm DF, and the pencil at C; and, if a copy were required of the same scale as the original, then, the sliding indices still remaining at the same divisions upon DF, and AB, the fulcrum must take the middle station, and the pencil and tracing point those on the exterior arms, AB and AC, of the instrument.

Part III.

ON SURVEYING.

CHAPTER I.

PRELIMINARY REMARKS ON SURVEYING IN GENERAL AND FIRST PRINCIPLES.

THE Practice of Surveying may be considered as divided into two branches, viz., such as is conducted on the principles of Spherical Trigonometry, and such as is carried on by the rules of Plane Trigonometry.

For the first, a very considerable acquaintance with Mathematics is essentially necessary, but for the second, a sufficient degree of perfection may be obtained by a competent knowledge of the rules of Plane Trigonometry.

The latter consists of four parts, viz. :

- 1st. Measuring straight lines.
- 2nd. Finding the position of these straight lines with respect to each other.
- 3rd. Laying down or planning upon paper their positions and measurements.
- 4th. Obtaining the superficial measure or area of the land surveyed.

Land Surveying may therefore be defined as the art which teaches us to find, how many times any customary measure is contained in a given piece of ground, and to delineate the true boundaries thereof in a Plan or Map, in such a manner,

that the horizontal dimensions of the features of the earth, may be measured by means of a scale, such as, territorial boundaries, rivers, lakes, roads, hills, forests, &c.

There are only two distinct methods, by which the dimensions of any piece of land can be taken, viz. :

1st. By the *Chain only*.

2nd. By the Chain accompanied with *angular instruments*.

Likewise there are only two distinct methods, by which the area or content of any piece of land can be ascertained, viz. :

1st. Arithmetically.

2nd. Geometrically, by measuring distances on its graphic representation.

As in the former, there are various ways of applying the two methods in practice, so in the latter, the means are equally at disposal.

“ The basis of an accurate survey, undertaken either for any extensive geodesical operation, such as the measurement of an arc of the meridian, or of a parallel; or for the formation of a territorial map, showing the positions of towns, villages, &c., and the boundaries of estates and counties; or a topographical plan for military or statistical purposes, must necessarily be an extended system of triangulation, the preliminary step in which is the careful measurement of a base line on some level plain: at each extremity of this base, angles are taken to several surrounding objects previously fixed upon as trigonometrical stations; and also, when practicable, the angles subtended at each of these points by the base itself. The distances of these stations, from the ends of the base line and from each other, are then calculated, and laid down on paper, forming so many fresh bases from whence other trigonometrical points are determined, until the entire tract of country to be surveyed is covered over with a net-work of triangles of as large a size as is proportioned to the contemplated extent of the survey, and the quality and power of the instruments employed. Within this principal triangulation secondary triangles are formed,

and laid down in like manner by calculation; and the interior detail is filled up between these points, either entirely by measurement with the Chain and Theodolite, or by partial measurement [principally of the roads,] and by sketching the remainder with the assistance of some portable instrument.

“In a flat uncleared country any attempt at a system of triangulation would be useless. In such cases the only mode of ensuring tolerable accuracy in surveys of great extent is that which has been generally adopted in the construction of geographical maps. The latitude and longitude of a number of the principal and most conspicuous stations are determined by astronomical observations, and the distances between them calculated to enable their positions to be laid down as correctly as they can be determined by this mode of fixing the relative place of each station. In surveying any extended line of coast, where the interior is not triangulated, no other method presents itself; and a knowledge of practical astronomy therefore becomes indispensable in this, as in all extensive geodesical operations.*”

In the year 1823, when the plan of a general survey for the whole of India was under discussion, and the first intimation given of the intention of the Court of Directors, of publishing a complete Indian Atlas, on the scale of 4 miles to the inch, the opinion and advice of that distinguished Geographer, Major Rennell, was obtained and in his Minute on the subject, he advocated precisely this method, and was all for an Astronomical basis as the only means of obtaining a geographical map of a country, not far short of four times the area of France, at a moderate expense and within a reasonable time.

“All idea therefore,” says Rennell, “of mensuration, or a series of triangles over the country is out of the question, and according to my opinion the only mode in which the work can be accomplished with such a degree of general accuracy, as is consistent with the required despatch, is to obtain in the first

* Frome on Trigonometrical Surveying.

instance a series of celestial observations of latitudes and longitudes, by which a sufficient number of *geographical points* at proper intervals may be determined in order to regulate the scale of the map, and to furnish the means of correcting that of the *cursor* surveys by which the intervals between those points must be filled up. They may also serve to regulate, or at least to assist in regulating the distribution of the space at large amongst the different Surveyors. The intervals are to be filled up by Compass Bearings, and by *time* employed as a means of distance (which habit will soon render familiar) by triangles formed in a coarse way, where the country is favorable by furnishing natural marks, and by latitudes and longitudes finally made *subsidiary* to the observations above contemplated." This opinion, however, he afterwards changed for one, on the Trigonometrical basis, a view taken subsequently by Lord William Bentinck, Governor General of India, in his masterly Minute on the subject, wherein he lays down the first principles on which a large country should be surveyed in the soundest and most practical manner. The system therein developed, however, was not followed out, in all its integrity, but the Grand Trigonometrical Survey was permitted to proceed, as a skeleton operation, and the result of the labors of Colonel Lambton from the commencement of the undertaking in 1799, to the present time is fully explained in the Asiatic Researches, by this celebrated Geodist, and by his successor, Lieut. Col. Everest, in his two "Accounts of the Measurement of an Arc of the Meridian" published in 1830 and 1848, respectively.

This survey therefore forms the framework into which the present Topographical or Revenue Survey of the present day identifies itself. All the districts coming under the Revenue Regulations of the Government both in Bengal and the North Western Provinces, may be said to consist for the most part of open cleared flat country, and *boundaries* being the chief object, a system of Periphery measurement is resorted to, which for

economy and facility of execution has been found to answer admirably, taking the enormous extent of work to be accomplished, and the urgent necessity for a first survey, into account. In hilly countries, however, this Indian system of Revenue Survey requires modification, it being obvious that all lines measured by the Chain must be reduced to the horizontal level; the angles of elevation therefore in such a country must be observed and registered, whereby the Hypothenusal Chain work may be reduced to the horizon in proportion to the co-sine of the angle of inclination. But even this precaution would not be satisfactory in very hilly and rugged ground, because the accumulation of Chain measurement error under such circumstances must necessarily be great, and moreover, on such ground, great facility for triangulation presents itself, and which gives horizontal distances at once, without further calculation or trouble, much more correctly than by any other process.

In addition to these more regular surveys, there are others of a more desultory nature, constantly going on in India. Route Surveys as conducted by the Quarter Master General's establishment, lining out new roads by the Executive Engineer's Department, and exploratory expeditions into new and unknown countries, for each of which we shall endeavour to lay down some useful rules for guidance.

In ordinary surveys it is not necessary to enter into calculations for the sphericity of the earth, nor indeed many other niceties required to perform any important Trigonometrical operation. On common occasions it suffices to consider the earth as a plane or flat surface, and all the sides of the triangles as right lines instead of curves, for a degree of $69\frac{1}{4}$ English miles, considered as a curve, measures but little more than 24 feet longer than its chord; we cannot therefore expect any series of linear measurements, with all possible care, to come nearer the truth than that when extended to several miles.

A Topographical Survey further requires that some of the party employed upon it, should be well versed in general outlines of geology, as a correct description of the soil and mineral resources of the different parts of every country forms one of its most important features. The heights of the principal hills, and of marked points along the ridges, plains, valleys and water-courses above the level of the sea, should also be determined, which on the Ordnance Survey of Ireland is done by levelling with the Theodolite. In a survey of less pretensions to correctness in minute detail, the heights may be ascertained with tolerable accuracy by means of the mountain barometer.

A sketch of a certain tract of country, on a far larger scale than that of most general maps, is constantly required on service, for the purpose of shewing the Military features of the ground, the relative positions of cities and villages, and the direction and nature of the roads and rivers comprised within its limits. This species of sketch, termed a "Military Reconnoissance," approaches in accuracy to a regular survey, in proportion to the time and labor that is bestowed upon it.

"Accurate surveys of a country are universally admitted to be works of great public utility, as affording the surest foundation for almost every kind of internal improvement in time of peace, and the best means of forming judicious plans of defence against the invasions of an enemy in time of war; in which last circumstance their importance usually becomes the most apparent. Hence, it happens that if a country has not actually been surveyed, or is but little known, a state of warfare generally produces the first improvements in its geography, for in the various movements of armies in the field, especially, if the theatre of war be extensive, each individual officer has repeated opportunities of contributing, according to his situation, more or less towards its perfection: and these observations being ultimately collected, a map is sent forth into the world considerably improved indeed; but which being

still defective, points out the necessity of something more accurate being undertaken when times and circumstances may favor the design.*

Having thus briefly remarked on the leading principles of the several modes of surveying, before proceeding with a description of them in detail, a few hints for the general guidance of the Surveyor, which experience has taught us to be worthy of adoption, may be given with advantage.

1st. The Surveyor should settle definitively in his own mind, the system of Surveying he intends pursuing, then the plan of operations he purposes in prosecuting the said system.

2nd. He should examine his instruments; see that they are all in proper order, and accurately adjusted, and compare his Chain carefully with the standard measure, correcting any error in it.

3rd. He should select, or instruct his assistants in the selection of their Station points, which he should be careful so to dispose, that the lines may pass clear of trees, houses, or other impediments, and the fewer that can be made use of, the less will be the labour of the Survey; it will also be more accurate, and less liable to errors, both in the field and office.

4th. The Station lines should always be as long as possible, where it can be done without rendering the offsets too large, and where great accuracy is required, these lines should be repeatedly measured, for every station line is usually the basis of succeeding operations.

5th. The Surveyor should so contrive his work, as to avoid the multiplication of small errors, and particularly those that by communication will extend themselves through the whole of his operations: he should always bear in mind, the principle of working from *whole to part*, and never from *part to whole*; by the former method, errors are subdivided, by the latter, the errors inseparable from even the most careful observations are constantly accumulating.

* Account of the Trigonometrical Survey of England.

6th. He should be especially careful in the manner of keeping his field book; every thing noted in it should be clear and explanatory, so as not to admit of doubt in the event of another person having to put up or plot work from it; a neat field book denoting the careful Surveyor, as much as a dirty and untidy one is proof of the contrary.

7th. The field work should be subjected to test as soon as possible, and any errors rectified by re-observation or re-measurement whilst on the spot; if delayed for any time, the difficulty and inconvenience of returning to the spot will be so great as to prevent a fair correction being made and accuracy will be sacrificed in consequence.

8th. At the close of a day's work, measure the Chain, and note in the field book the quantity it may have stretched, so as to make allowances in any calculations that have to be made from measurements taken with it.

9th. The Surveyor should never allow himself to get into the habit of making his observations, whether angles or bearings, in a careless manner, under the impression that a small error in one observation will perhaps counterbalance itself in the next; he will find it more profitable in the end, to make *ten* careful observations during a day's work, than a *hundred* careless ones; the same remarks hold good for Chain measurements.

10th. No observation, memorandum, or note, should ever be recorded on slips of paper, and rejected, or be thrown aside as unimportant or useless; it is too commonly the practice to do this, but the time may come when the Surveyor would hail with delight the recovery of the remarks or calculations however roughly noted, which before he had thrown away; nothing can be too minute or too trifling to insert in the field book, whatever attracts the eye in the field, or comes within reach of the ear, should be so entered, as to be useful and intelligible to others as well as to himself at any future moment.

Lastly. A Surveyor should always endeavour to obtain a good knowledge of his District, or the portion of country under survey, by constantly riding over it, in every direction, and thus getting a sort of bird's-eye view in his own mind, this will enable him to check any glaring omissions in the maps produced by his subordinates, and give him a great advantage in prosecuting his operations, and making the best disposition of his work. In large establishments, such as those of the Revenue Surveys now in progress, composed of large bodies of Native, East Indian as well as European Assistants, the best results may be expected from an active personal supervision in the field, and indeed without this there can be no hope of proper and systematic progress or of the quantity of work which is performed being at all satisfactory or trustworthy.

In hilly countries more especially, the eye of the Superintending Officer must be abroad to render the Topography of his maps of any value; where the Surveyor himself does not take a part in these duties, and animate his European and East Indian Assistants by his example, it will be found that they, in turn, will devolve all the laborious and irksome duties on the Native Assistants, who soon become careless and indifferent when they find themselves uncontrolled.

When once a Surveyor contents himself with ordering and directing others to do, what he never thinks of undertaking himself, he may rest assured that it never will be done well. The first principle in the life of a Surveyor should be, to make a practice of putting his own shoulder to the wheel, and then to expect and demand equal zeal from his subordinates.

At the commencement of his professional career, a Surveyor will meet with many obstacles and annoyances, and frequently find himself placed in most trying circumstances, such as will almost induce him to relinquish the task he has in hand, but he must make up his mind to this and endeavour to overcome them, and not despair of success, because threatened with apparently insuperable difficulties, the pleasure of looking

back on an accomplished task, will always be heightened by the amount of difficulty overcome, or the remembrance of peculiar obstacles successfully contended against. All beginners should take encouragement from the fact of hundreds of men having commenced their career in perfect ignorance of the various duties they may have been called on to perform, and which by dint of industry and perseverance they have finally triumphed over and completely mastered.

CHAPTER II.

ON SURVEYING BY THE CHAIN ONLY.

IN making a Survey with the Chain only, we are confined to one, and the simplest geometrical figure, viz., the triangle, for of all plane geometrical figures, it is the only one of which the form cannot be altered, if the sides remain constant. That the triangle possesses this property is evident from the Theorem (Euclid 7. 1.) which proves that "Upon the same base, and on the same side of it, there cannot be two triangles that have their sides, which are terminated at one extremity of the base, equal to one another, and likewise those which are terminated in the other extremity, equal to one another."

The surface to be measured is therefore to be divided into a series of imaginary triangles; and in this division it must be borne in mind that the triangles are to be as large, with reference to the whole surface to be measured, as is consistent with the nature of the ground; for, by such an arrangement, we are acting on the important principle in all Surveying operations, (Page 237) that it is well always to work from *whole to part*, and rarely from *part to whole*.

The sides of these triangles are first measured, and as a necessary check, on this first part of the work, a straight line is in addition measured from one of the vertices to a point in or near the middle of the opposite side. This fourth line is called a tie-line, and is an efficient means of detecting errors if any have been committed in the measurement of the sides of the triangle. This fourth measurement is made in accord-

and with a maxim which ought invariably to be acted upon in all Surveying operations, viz., that where accuracy is aimed at, the dimensions of the main lines, and the positions of the most important objects, should be ascertained or tested by at least two processes independent one of the other. Within the larger triangles, as many tie-lines and smaller triangles are to be measured as may be necessary to determine the position of all the objects embraced in the Survey. The directions of the lines forming the sides of these secondary triangles are so selected or disposed that they shall connect, and pass close by, as many objects as possible, so that the offsets to be measured from them may be as short and as few in number, as practicable.

If the sides of these secondary triangles be in any case so distant from the objects whose positions are to be determined as to require a length of offset greater than one or two chains, it then becomes advisable to construct, either on the whole or a part of the side of the triangle as a base, a smaller offset triangle with the sides so disposed that they shall either embrace, or pass very near to the objects to be measured by their intervention.

The disposition and general combination of these triangles demanding care and judgment, it is customary, previous to commencing any measurement, to walk over the ground for the purpose of obtaining a general knowledge of the surface, and of the relative positions of the most conspicuous objects. The acquisition of this knowledge depending on the *coup d'œil*, is much assisted by an eye-sketch drawn with rapidity, and showing some of the principal roads, streams, temples, &c.

This hand-sketch is not to be drawn to any scale, and its object is attained if it simply bear a general resemblance to a plan of the ground, as it will thereby assist the memory in the distribution of the surface into triangles.

The sides of the larger triangles are to pass as close as possible to the external boundaries to be surveyed; the triangles

should moreover be made to approach, as nearly as practicable, to the form of equilateral, avoiding with care very acute or very obtuse angles, because the farther the form of the triangle is removed from the equilateral, the greater will be the alteration in the form of the figure and in its area, should any error have been committed in the measurement of any one of the sides.

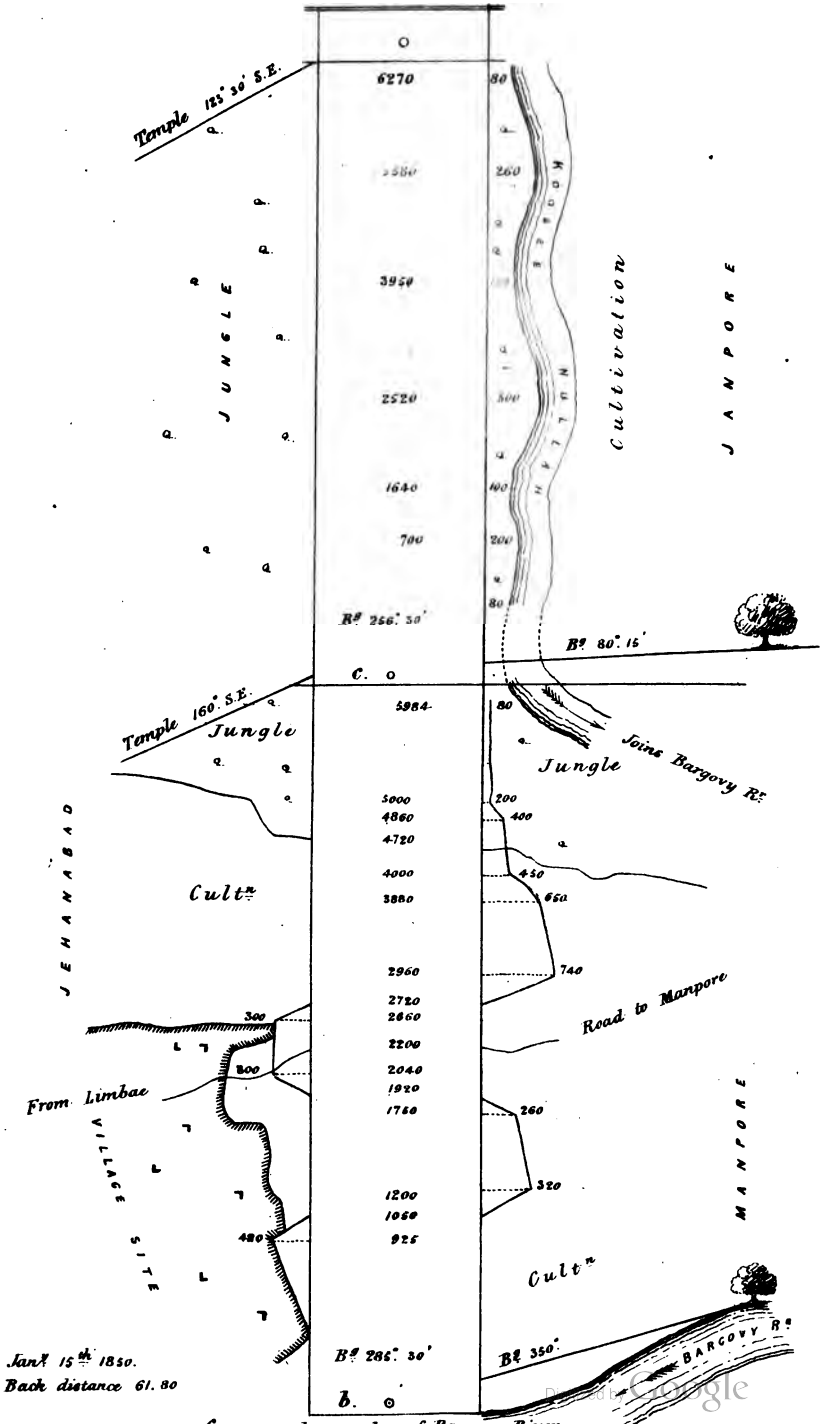
The triangles having thus been disposed to the greatest advantage, marks or pegs are placed in the ground at each vertex of the triangles; their general form, or position is then noted on the hand-sketch previously made, and distinctive letters are written on the diagram at each point of intersection; this arrangement admits of easy reference in the Field-book, or on the ground, to any triangle or part of a triangle.

The points of intersection of all straight lines, as well as the vertices of the triangles, are always points measured *to* or *from*: they are called Station points, and the lines connecting them. Station lines, thereby distinguishing them from the simple offset lines. Stations are generally expressed by letters, main stations by capital or roman letters A, B, C, &c. and secondary stations by small letters *a*, *b*, *c*, &c.

The hand-sketch, or rough diagram, is usually made in a Field-book, *i. e.*, a book in which every minute step of the operations gone through, is to be entered with precision at the time.

This Field-book should be of a convenient size for the pocket, having the page ruled with a central column; this central column is intended for all actual lines measured, and by commencing from the bottom of the page, the page becomes a smaller representation of the reality, with the line measured from you, and the offsets at their respective distances on that line, taken at so many links to the right or to the left, as they actually are on the ground and noted to the right or left of the central column.

In keeping the Field-book, it first should ever be remembered that the central column is virtually but *one* line represent-



Jan 15th 1850.
Back distance 61.80

Commenced on edge of Bargovy River
at Station b, of 14th Jan^y

ing the Chain, the space within the column being merely required for the several distances on the Chain, whence the offsets are taken, and secondly, that all offsets read either way *outward* from the centre column, in the same way as they are measured *outward* from the Chain; if the station line, therefore should be crossed on the ground by a road or any boundary meeting it obliquely, its representation or type in the Field-book must not be made to pass obliquely across the middle column, but must arrive at one side of the column and leave it on the other, at points precisely opposite, as it would do were the middle column merely of the thickness of a line; inattention in this particular, causes much confusion in the relative position of offsets.

To preserve uniformity, as it is more natural to measure from left to right, the place measured *from* is put on the *left* of the central column at the bottom of the line, and the station measured *to* is put at the top to the *right*; the points of commencement and termination of the line can thus be immediately seen.

The book should be interleaved with blotting paper and the entries made in ink or inked in the same day on return from the field, the pages should also be numbered for facility of reference and each day's work dated.

If the direction of the line is determined by an angle taken with a Theodolite, or the bearing of the line be given by the Circumferentor or other instrument, the angle of the former, or bearing of the latter, is placed in the central column immediately above the starting point.

In taking offsets to corners of boundary marks or other objects, mark the relative position of the corner or object as to the Chain line, and generally be careful to make the Field-book as much as possible a *fac simile* of the ground itself, with each boundary mark, &c., placed on the book, as to the central column, *considered always as one line*, in the same position as they stand to the Chain on the ground; no time is

gained to the Surveyor by hurrying over the notes in the Field-book, a little care in the field saving much trouble in office.

It cannot be too strongly impressed on the Surveyor that the work which he is called upon to perform depends for its accuracy in a very great measure on the order, system, and neatness bestowed on all the steps whether of delineation or measurement; proper attention in keeping the Field-book saves much time in plotting and guards against the errors unavoidably arising from reference to a confused Field-book; moreover, care bestowed in the first essays, will amply reward the Surveyor, by giving accuracy of eye, freedom and steadiness of hand, qualities indispensable to his success.

Having given various examples under the head of "Useful problems in Surveying" (page 66) of surveying small fields by the Chain only and also instrumentally, we will here give an example of surveying a larger tract of country by the Chain only, and in which we will also show the method of filling in one of the triangles of the Survey.

The example given is that of a portion of country, comprising some 80 or 100 fields, 6 or 8 roads, a village, river, canal, and a line of railroad running through a corner of it towards the village.

The first thing to be done, is to select a line of country free from obstacles, such as houses, underwood, &c., and running (if practicable) through the greatest extent of the property to be surveyed, with the view of measuring a Base line, on which line all the principal triangles should be formed as nearly equilateral as possible; this line should also run as nearly as possible through the centre of the property and its direction should be for a principal object beyond its termination, such as the steeple of a church, corner of a house, or some remarkable object.

In the diagram on the adjoining Plate, AB has been selected as the Base line, running through the whole of the Survey,

intersecting the road HC at C, the road GK at D, and the road MO at E, which distances are carefully marked in the Field-book.

Where this Base line crosses the boundaries of fields at the most favorable place for running cross lines along these boundaries, stakes must be put in, and the points carefully noted, taking offsets *en route* to any corners or other objects that may be within an offset distance.

The method actually adopted would be, in order to avoid any needlessly going over the same ground twice, to commence at A, measure AN, NVH, then HC, CV, and the fields within the block VCH and NCV.

From H, the next line measured would be HG, observing carefully where the best stations could be taken for the cross boundaries, on the same side of them, as the stations were selected in the Base line.

Then measure GD and HD, observing, in measuring HD, to have the range of the line carefully defined, where the several boundaries cross, so as accurately to define the several points in the line CD, where the cross boundary-lines, from AB to HG, intersect. By this plan, all these cross-lines are check-lines.

Produce GD to K, in the same straight line; measure KC, taking notice as before, where the cross boundaries come, and on their proper side, and complete the block HGKC.

Then measure CL and LK.

Now return to G, and produce HG to F, where it intersects the Base line; marking the several points P, Y, and X, upon it, and the several cross boundaries.

Then from D produce HD to M; join MK, and from M, measure a line in range with EX, which produce to O; join OB; then complete the block GXMD, and the triangular piece KDM.

There now remains but the part adjoining the village.

From P, measure PRS, and join ST; then produce YR to *b*, and join *ba*; the lines *ba*, *aT*, TS, SR, R*b*, will tie the whole of the houses in. This must always be the plan adopted in the survey of a village, to confine all the areas within one triangle, whose three sides should severally pass through the principal points of the place.

Having given the method adopted in practice, for saving time in the survey of the plan, we will proceed to explain the nature and use of the several main lines.

The line ME, of the triangle DME, is the measure of the angle MDE; but CH, in the triangle CHD, is the measure of the opposite and equal angle CDH. Therefore the measured and determined distance, agreeing or disagreeing of either side CH or ME, is a proof of the correctness or incorrectness of the angle at the vertex D.

Produce ME, the fixed line, to O; any points upon this production are also fixed. The point X, which is in a range with the road HP, is fixed; and H, being a fixed point, the length of HX is determined.

Its measurement becomes a line of verification to the opposite angle HMX, or (MDE being supposed correct) of the supplemental angle DEM: which is the angle that this new line MD makes with the Base line. The line OB, if the nature of the ground will permit its being measured, measures the opposite angle BED, and is another check upon its correctness.

Again, MX is the measure of the angle MHX; and GD is also the measure of the same angle.

The actual distance of GD, compared with its computed or determined distance is a check upon the correctness of the length of MX.

Having determined the correctness of these triangles, there can be no error of any moment in the filling in.

In fact, all the lines used for the measurement of the offsets to the cross boundaries, are only so many additional check

lines to the triangles, or measures of the angles at their vertices.

CK being determined by the previous measurements, its measured distance is a check upon the angle CDK, and, therefore, upon the direction of the line KC, relative to the Base line AB.

The correctness of the triangle, CLK, is secured by the check-line to its vertex LC.

The triangle ANC, having in AC a portion of the Base line, depends upon the correctness of the measured distances AN and NC.

A, being thus a fixed point, as well as H, measure the line NH, and as H has been previously assumed correct, HN is a measure of the angle NCH, which is the supplemental angle to the two and known angles HCD, ACN; the length VC is a check upon the distances CN and CH.

Now returning to the other parts of the survey, the line HX, produced to the Base line at F, is an additional verification of the whole of the triangulation.

To ensure a correct survey of the village, observe that the line MO α passes close to one side of it.

From P, drawing PRS through R, and joining ST, we have known lines close to the village, on another side; producing YR to a point *b*, such that a line *ba* shall pass close to the third side of the village, we surround the whole with a fixed triangle. All errors must be confined within this limit; and all lines, for the measurement of the houses or roads, carried through to either of the sides of this triangle, are, as in the case of the cross boundary-lines in the first part of the survey, virtually but so many corroborative checks of its accuracy.

The principal lines being thus measured, we proceed to fill in one of the triangles such as CDK; for this purpose commence at any of the angular points of the triangle such as K, and run a line K α to the opposite side CD, leaving marks at the

crossing of all boundaries of fields, such as *c* and *d*, taking offsets to all objects within ordinary distance. When this line is measured up to the side *CD*, stop, and from the point *a*, measure the distance on the line *CD*, up to the nearest mark *b*, previously made on the line *CD*, and enter this distance, and the length of the line *Ka* in the Field-book. From the point *a* run a line *ae*, leaving a mark at *f*, and when arrived at *e*, perform similar work as done at *a*, after the same manner measure also the lines *fb*, *be*, *fK*, and *dD*, and so proceed until the position of all the boundaries and other objects within the triangle *CDK*, are determined.

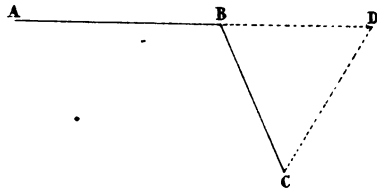
Thus are all the sides of the triangles measured in succession, and their dimensions with the additional assistance of the offsets, give the means of ascertaining all boundaries, external and internal, positions of houses, &c., and of finding the area of the whole and of every part, by direct computation from the Field-book. But to obtain the contents of each field or enclosure by computation, would be a process very laborious and generally unnecessary: the contents of the whole should be ascertained by computation from the sides of the large triangles: the areas of the inclosures may be afterwards obtained by measurement from the plan, by dividing them off into small triangles (page 65,) their accuracy being tested by a comparison of the sum of the areas of each inclosure with the area comprised within the exterior boundary, as obtained by direct computation.

CHAPTER III.

ON SURVEYING BY THE CHAIN, ACCOMPANIED WITH ANGULAR INSTRUMENTS.

THE method of surveying by the Chain *alone* is applicable only to Surveys of comparatively small extent and simple in their outlines, for even in small Surveys, the intervention of villages, high inclosures, temples, topes of trees, or other obstacles, may be found to render the measurement of right lines by the Chain extremely difficult, and by isolating different portions of the work, to cause inaccuracies that may be avoided by the use of an angular instrument.

Angles it is true may be determined by the Chain alone, by measuring the sides of small triangles disposed for the purpose, thus: Let AB, represent a line measured to a station B, from whence a second line BC, forming an angle with AB, is to be measured. To determine the angle ABC, prolong AB to D, make BC equal to BD, and measure the chord DC; the three sides of the triangle BDC being known, the angle DBC or its supplement ABC is determined.



This is a method which ought, however, rarely to be resorted to, for no time is gained by its adoption, and the chances of error are considerably multiplied, owing to the numerous

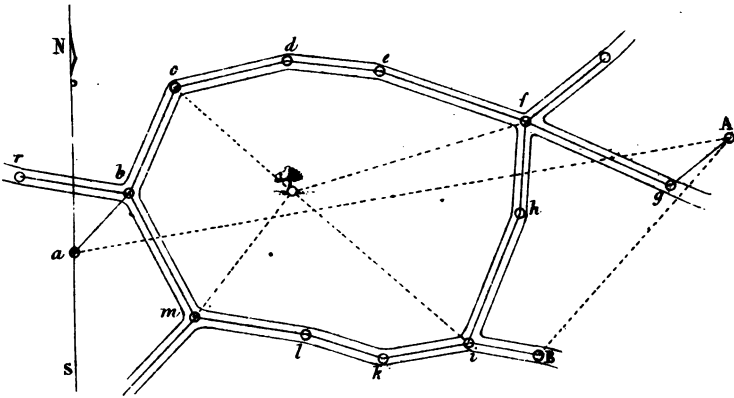
additional lines to be measured; moreover, it is to be observed, that angles can in general be measured in the field more correctly with an instrument than the length of lines with the Chain, especially over uneven ground or in an inclosed country.

The instrument in general use, for the purpose of measuring angles in Surveying, is the Theodolite. It is calculated for extreme accuracy, and should always be used when quality and not quantity is the desideratum; when the correctness of the result, and not the rapidity of execution, is the object.

In broad and extensive flats, though the triangulation were better carried on by the Chain, as the Chain is indispensable for determining cross boundaries, &c., yet the long lines of the triangulation must always be run in by the Theodolite.

In broken and hilly countries where the Chaining could only be obtained by an application of the angles taken by the Theodolite to the determining of the comparative lengths of the hypotenusal to the horizontal lines, this instrument is indispensable. The correct length of one side of a triangle together with the measures to minutes and half minutes, obtained with the accuracy of which a good Theodolite is susceptible, of its two adjacent angles, will always more certainly determine the position of a third point, when hills intervene, than the incorrectly measured distances of the two other lines.

The various uses to which the Theodolite can be applied, in finding distances across rivers, heights of inaccessible objects, &c., are given under the head of "Heights and Distances" (page 55,) and of "Useful problems in Surveying" (page 66,) the adjustments of the instrument also, and methods of observing angles (pages 124 and 132,) it is therefore unnecessary to dilate further on its application to Surveying, beyond giving an example, describing the method of proceeding with it.



Let the above plan represent a Survey of roads to be performed with a Theodolite and Chain. Commencing on a conspicuous spot *a*, near the place at which two roads meet, the Theodolite must be set up and levelled, the upper and lower horizontal plates clamped at zero, and the whole instrument turned about until the magnetic needle steadily points to the NS line of the compass-box, and then fixed in that position by tightening the clamp-screw *H*. Now release the upper plate, and direct the telescope to any distant conspicuous object within or near the limits of the survey, such as a pole purposely erected in an accessible situation, that it may be measured to, and the instrument placed upon, the same spot at a subsequent part of the operation, as *A* and *B*, and after bisecting it with the cross-wires, read both the verniers of the horizontal limb, and enter the two readings in the Field-book; likewise in the same manner take bearings, or angles, to all such remarkable objects as are likely to be seen from other stations, as the tree situated on a hill; and lastly, take the angle to your forward station *b*, where an assistant must hold a staff for the purpose, on a picket driven into the ground,* in such a situation as will enable you to take the

* A picket should always be left in the ground at every station, in order to recognise the precise spot, should it afterwards be found necessary to return to it again.

longest possible sight down each of the roads that meet there. In going through the above process, at this and every subsequent station, great caution must be used to prevent the lower horizontal plate from having the least motion after being clamped in its position by the screw H.

Next measure the distance from a to b , and set up the instrument at b , release the clamp-screw H *only*, not suffering the upper plate to be in the least disturbed from the reading it had when directed at a to the forward station b , with the instrument reading this forward angle; turn it bodily round, till the telescope is directed to the station a (which is now the back station) where an assistant must hold a staff; tighten the clamp-screw H, and by the slow-motion screw I, bisect the staff as near the ground as possible, and having examined the reading, to see that no disturbance has taken place, release the upper plate, and setting it to zero, see if the magnetic needle coincides, as in the first instance, with the NS line of the compass-box; if it does, all is right; if not, an error must have been committed in taking the last forward angle, or else the upper plate must have moved from its position before the back station had been bisected: when this is the case, it is necessary to return and examine the work at the last station. If this is done every time the instrument is set up, a constant check is kept upon the progress of the work; and this indeed is the most important use of the compass. Having thus proved the accuracy of the last forward angle, release the upper plate, and measure the angles to the stations m and r , and, as before, to whatever objects you may consider will be conspicuous from other places; and lastly, observe the forward angle to the station c , where the Theodolite must next be set up, and measure the distance bc .

At c , and at every succeeding station, a similar operation must be performed, bisecting the back station with the instrument reading the last forward angle; then take bearings to every conspicuous object, as the tree on the hill, the sta-

tion A, &c. which will fix their relative situations on the plan, and they afterwards serve as fixed points to prove the accuracy of the position of such other stations as may have bearings taken from *them* to the same object; for, if the relative situations of such stations are not correctly determined, these bearings will not all intersect in the same point on the plan. The last operation at each station is to measure the forward angle. In this manner proceed to the stations *d, e, f, g, &c.*, and having arrived at *g*, measure an angle to the pole A, as to a forward station, and placing the Theodolite upon that spot, direct the telescope to *g*, as a back station, in the usual way; this done, release the upper plate, and direct the telescope to the *first* station *a*, from which A had been observed, and if all the intervening angles have been correctly taken, the reading of the two verniers will be precisely the same as when directed to A from the station *a*: this is called closing the work, and is a test of its accuracy so far as the angles are concerned, independent of the compass needle. If the relative situation of the conspicuous points A, B, &c. were previously fixed by triangulation, there would be no necessity to have recourse to the magnetic meridian at all, as a line connecting the starting point *a* with any visible *fixed* object, may be assumed as a working meridian, and if it be thought necessary, the reading of the compass-needle may be noted at *a*, when such fixed object is bisected and upon the Theodolite being set to the reading of this assumed meridian, at any subsequent station, the compass-needle will also point to the same reading as it did at first, if the work is all correct, and no local attraction influences the compass.

While the instrument is at A, take angles to all the conspicuous objects, particularly to such as you may hereafter be able to close upon, which will (as in the above instance) verify the accuracy of the intervening observations; having done this, return to *g* and *f, &c.* and proceed with the Survey in the same manner as before, setting the instrument up at

each bend in the road, and taking offsets to the right and left of the station lines ; arriving at i , survey up to, and close upon B ; then return to i , and proceed from station to station till you arrive at m , where, if the whole work is accurate, the forward angle taken to b will be the same as was formerly taken from b to m , which will finish the operation.



CHAPTER IV.

ON PLOTTING.

In the execution of extensive Surveys upon scientific principles, the accurate measurement of angles is of the utmost importance, requiring the employment of instruments of a superior construction, as well as considerable care and skill in their management; and one great object of such Surveys, being the correct formation of Maps and Charts, it is no less essential, that the angles, when accurately measured, should be accurately laid down.

As the instruments therefore necessary to be used by the Surveyor in taking dimensions of land, are such wherewith he may measure the length of a side, and the quantity of an angle in the field; so the instruments commonly used in making a plot or draught thereof, are such wherewith he may lay down the length of a side, and the quantity of an angle on paper. They therefore consist in scales of equal parts for laying down the lengths or distances, and protractors for laying down the angles. The various kinds of scales and protractors in general use with Surveyors will be found explained in Part II. of this work.

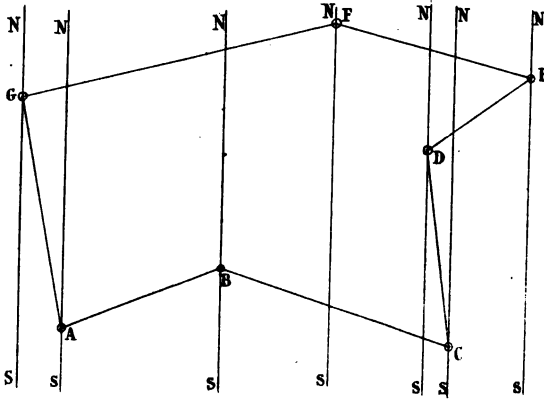
The common method of plotting is this: Take a sheet of paper of convenient size, draw a line thereon, to represent the magnetic meridian, and assign any convenient point on this line to represent the place where the Survey commenced; lay the edge of the rectangular protractor on this meridian line, and bringing the centre thereof to the point assigned to represent the place of beginning, mark off the degrees and minutes

of the first bearing by the limb of the protractor, and draw a line from the place of beginning through the point so marked, laying off its proper length or distance by the scale of equal parts; this line will represent the first line of the Survey.

Through the point or termination of the said first line of the Survey draw another line, representing the magnetic meridian, parallel to the former, and lay off the bearing of the second line of the Survey by the protractor, and its length by the scale of equal parts, as before, and so proceed, until the whole is laid down.

For Example.—Let it be required to make a plot of the following Field notes:—

Line.	Line.
AB — N. E. $52^{\circ} 00'$ Dist. 9.17 Chs.	EF — N. W. $297^{\circ} 30'$ Dist. 14.40 Chs.
BC — S. E. $106^{\circ} 15'$ „ 12.04 „	FG — S. W. $235^{\circ} 15'$ „ 18.20 „
CD — N. W. $355^{\circ} 45'$ „ 14.00 „	AG — S. E. $173^{\circ} 00'$ „ 21.00 „
DE — N. E. $40^{\circ} 00'$ „ 11.00 „	



1st.—Draw any line as NAS to represent the magnetic meridian, and assign any convenient point thereon as A to represent the place of beginning the Survey; lay the edge of the protractor on the line NAS, with the centre thereof at the point A and mark off 52° on the limb to the eastward, and draw the line AB through the point so marked off, making the length thereof 9.17 Chains by the scale of equal parts.

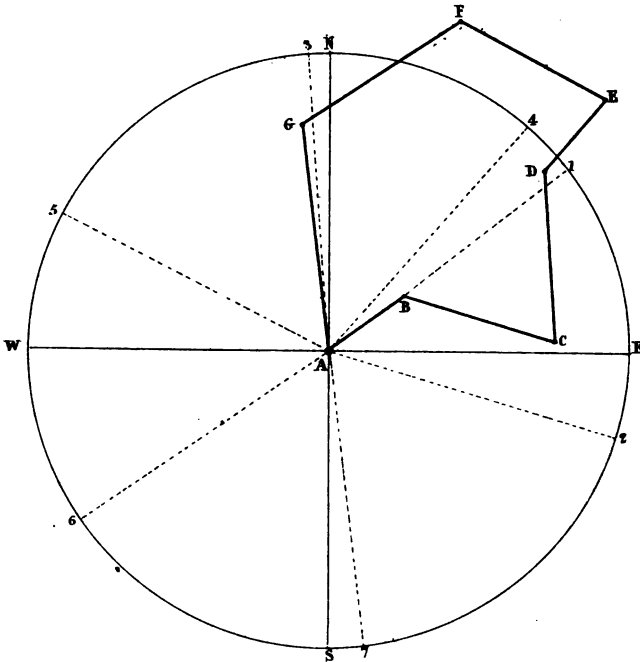
2nd.—Draw another meridian line NBS, through the point B, parallel to the former. Lay the edge of the protractor on this second meridian line NBS with the centre thereof at the point B, and mark off $106^{\circ} 15'$ to the eastward, and draw the line BC, through the point so marked off, making the length thereof 12.40 Chains by the scale of equal parts.

3rd.—Draw another meridian line NCS, through the point C, parallel to the former, lay the edge of the protractor to this third meridian line NCS, with the centre thereof at the point C, and mark off the third bearing $355^{\circ} 45'$ to the westward, making the length of the line CD 14.00 Chains in the same manner as before, and so proceed with all the other lines DE, EF, FG and GA, and if the last line terminates in the place of beginning or at the point A, the work is said to *close*, and all is right; but if the last line does not terminate in the place of beginning, there must have been a mistake, either in taking the Field-notes, or in the protraction of them; in such case therefore, it will be necessary, to go over the protraction again, and if it is not found, the mistake must be in the Field-notes, to correct which, they must be taken again.

This method of plotting is liable to some inaccuracies of practice, on account of having a new meridian for every particular line of the Survey, and on account of laying off every new line from the point of termination of the preceding one, whereby any little inaccuracy that may happen in laying down one line is communicated to the rest.

These inaccuracies or errors of plotting may be partly obviated where the Survey is not very extensive by the use of the circular protractor, and having only one meridian line assigning a point thereon for the beginning of the Survey, all the bearings are laid off at once from this point, and the other points of the Survey fixed, by means of lines drawn parallel to the bearings, as laid off from the first point.

For instance, let it be required to make a plot of the Field-notes as given in the last example.



Draw a meridian line NS, and assign thereon a point A, as the beginning of the Survey, on this point A, place the centre of the circular protractor, with 360° exactly to the North, and 180° to the South of this line NS, mark off all the bearings of the lines AB, BC, CD, &c., beginning with the first and numbering it 1, the second 2, and so on. Then laying aside the protractor, cast the eye about the tract traced by the protractor for the bearing marked 1, draw a line from the beginning of the survey or point A, in the direction of the mark 1, and on it, lay off the distance 9.17 Chains, thus fixing the point B. Apply a parallel rule to the point A, and the mark 2, and move its edge up, until it touches the point B, last fixed; draw a line eastward and lay off from the point B, 12.40 Chains, thus fixing the point C.

Again, apply the parallel rule to the point A and mark 3, and move its edge up, until it touches the last point fixed or

C, draw a line thence northward and lay off on it the distance 14.00 fixing the point D.

In the same manner, apply the parallel rule to the point A, and the several other bearings, marked 4, 5, 6 and 7, and lastly, the bearing from the last point fixed, or point G, will fall exactly into the first, which closes the plot; it is almost unnecessary to observe, that the dotted lines in the diagram, are drawn only to illustrate the operation, and that in practice it is only necessary to mark the numbers 1, 2, 3, &c., round the tract traced by the protractor.

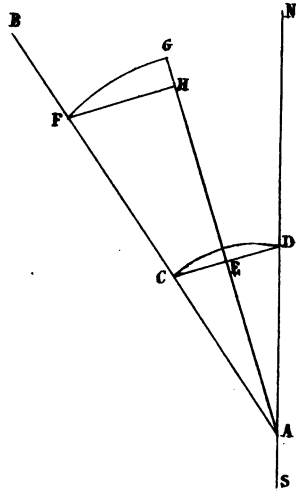
This method, now in general use among Surveyors, saves the trouble of shifting the protractor at every bearing and also insures greater accuracy in the plotting, as a great number of bearings being laid down from one meridian, a trifling error in the direction of one line does not affect the next; the accuracy of the plot, however depends much upon using a parallel rule that moves truly parallel, which it is well to look to before proceeding to this mode of plotting.

Triangles are more accurately protracted by means of their sides than by their angles, and one side only, for measures of length can be taken from a scale and transferred to paper with more exactness than an angle can be pricked off from a protractor.

In plotting an extensive survey, it is in most cases requisite to show the direction of the meridian and it therefore becomes necessary to lay down from one of the principal stations the azimuthal angle subtended by some other station and the meridian: now this angle cannot be laid off from a protractor, even of the most approved construction, so accurately as the plotting of the triangulation may be made from the measured or computed sides of the triangles. To obtain a corresponding degree of exactness, recourse must be had to some other method, and the following described by Mr. Simms* is the best that we have seen practised.

* Treatise on Surveying Instruments, &c.

Let AB be the side of a triangle, the azimuthal angle of which has been ascertained with reference to NS , the meridian line. Take from an accurately divided diagonal scale, exactly 5 inches as a radius, and from A , as a centre, describe an arc CD ; now the chord of an arc being equal to twice the sine of half the arc, the chord CD is equal to twice CE , the sine of half the angle CAD . Take a radius AF equal to twice AC , and describe the arc FG intersecting the radius AB in F , draw the sine FH , then by similar triangles,



$$AF : AC :: FH : CE, \text{ but}$$

$$AF = 2AC \text{ by construction, therefore}$$

$$FH = 2CE = CD;$$

that is, the chord of a given arc is equal to the sine of half the arc with double the radius.

The radius of the tables of natural sines is equal to 1 or 10; and having taken the half of 10 or 5 inches for the radius AC , the natural sine of half the given angle taken from the tables will correspond to FH , the sine of half the given angle with double the radius; but FH was proved equal to CD ; the natural sine therefore of half the given angle to a radius 10, will be equal to the chord of the whole angle to a radius 5. Having taken that distance from the same scale of inches as the radius, place one foot in the point C , and with the other mark the point D on the arc CD , then through D and A draw the line NS , which will be the direction of the meridian.

This method of laying off angles may also be conveniently employed in dividing a circle to be used as a protractor, and

which can be made either on the same sheet of paper, intended to receive the drawing, or on a separate sheet of card-board, when it may be preserved and used on after occasions. The great difficulty of dividing a circle accurately is well known, but if the arcs are laid off by means of their chords, the division may be performed with great exactness.

A protractor laid down upon the paper, enables the draftsman to plot the work with great rapidity, and with less chance of error, when the scale is small, than by the method of laying off angles by placing the centre of a metallic protractor at every angular point, and pricking off the angle from its circular edge.

During the time which must necessarily be occupied in plotting an extensive and minute Survey, the paper which receives the work is often sensibly affected by the changes which take place in the hygrometrical state of the air, causing much annoyance to the draftsman, as the parts laid down from the same scale at different times will not exactly correspond. To remedy in some measure this inconvenience, it has been recommended that the apartments appropriated to the purposes of drawing, should be constantly kept in as nearly the same temperature as possible and also that the intended scale of the plan should be first accurately laid down upon the paper itself; and from this scale all dimensions for the work should invariably be taken, as the scale would always be in the same state of expansion as the plot, though it may no longer retain its original dimensions.

Another method of protracting a Survey, and by which the inconveniences of the above methods are avoided, and by which also the accuracy or otherwise of the Field-work is decided with precision and certainty, will be presently treated of, in the meanwhile we refer the reader to Chap. 8 and 9, Part II., where, in describing the use of the several instruments used in plotting, further instructions are given, and close this chapter by extracting from Mr. Bradley's valuable

work on Practical Geometry, the following useful rules, applicable to Geometrical construction :

1. Arcs of circles, or right lines by which an important point is to be found, should never intersect each other very obliquely, or at an angle of less than 15 or 20 degrees; and, if this cannot be avoided, some other proceeding should be had recourse to, to define the point more precisely.

2. When one arc of a circle is described, and a point in it is to be determined by the intersection of another arc, this latter need not be drawn at all, but only the point marked off on the first, as it is always desirable to avoid the drawing of unnecessary lines. The same observation applies to a point to be determined on one straight line by the intersection of another.

3. Whenever the compasses can be used in any part of a construction, or to construct the whole problem, they are to be preferred to the rule, unless the process is much more circuitous, or unless the first rule (above) forbids.

4. A right line should never be obtained by the prolongation of a very short one, unless some point in that prolongation is first found by some other means, especially in any essential part of a problem.

5. The larger the scale on which any problem, or any part of one, is constructed, the less liable is the result to error: hence all angles should be set off on the largest circles which circumstances will admit of being described, and the largest radius should be taken to describe the arcs by which a point is to be found through which a right line is to be drawn; and the greater attention is to be paid to this rule, in proportion as that step of the problem under consideration is conducive to the correctness of the final result.

6. All lines, perpendicular or parallel to another, should be drawn long enough at once, to obviate the necessity of producing them.

7. Whenever a line is required to be drawn to a point, in order to insure the coincidence of them, it is better to com-

mence the line from the point; and if the line is to pass through two points, before drawing it the pencil should be moved along the rule, so as to ascertain whether the line will, when drawn, pass through them both. Thus, if several radii to a circle were required to pass through any number of points respectively, the lines should be begun from the centre of the circle; any error being more obvious when several lines meet in a point.

CHAPTER V.

ON OFFSETS, AND THE VARIOUS PRACTICAL METHODS OF FINDING AREAS, INCLUDING THE REDUCTION OF INCLINED TO HORIZONTAL PLANES.

THE area of the principal triangles in a Survey, should, in all cases, be computed from the length of their sides, as obtained from the Field-book. The operation is simple, by the following rule:—

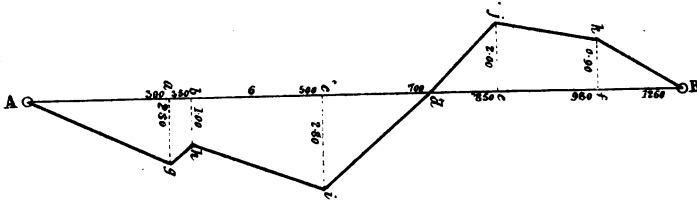
Rule.—Add the three sides together, from half the sum of the sides subtract each side severally. Multiply the half sum and three remainders together, the square root of their product will be the area, or—

By Logarithms, which method is a much shorter calculation than the former: To the Logarithm of half the sum of the sides, add the Logarithms of the three remainders, the sum of these Logarithms divided by 2, will be the Logarithm of the area.

To find the area of offsets by calculation: Multiply half the sum of each successive pair, by the distance on the Chain line between them, the sum of all these separate areas, will give the area of the whole offset on the Chain line.

EXAMPLE.

Let the subjoined plot of Field-notes represent the Offsets taken to a boundary on the station line AB.



Then, to the right of the Chain line,

	Acres.
$Aa \times ag$ or $3 \cdot 00 \times 2 \cdot 50 =$ double the Area of Triangle Aag or $0 \cdot 75$	
$Ab - Aa = ab \times \frac{ag + bh}{2}$ or $0 \cdot 50 \times 3 \cdot 50 =$,, Trapezoid, $bagh$,, $0 \cdot 175$	
$Ac - Ab = bc \times \frac{bh + ci}{2}$,, $1 \cdot 50 \times 3 \cdot 80 =$,, ,, $bhie$,, $0 \cdot 57$	
$Ad - Ac = cd \times ci$,, $2 \cdot 00 \times 2 \cdot 80 =$,, Triangle, dci ,, $0 \cdot 56$	
	2) 2·055
	Area, = 1·027

And to the left of the Chain line,

	Acres.
$Ac - Ad = de \times ej$ or $1 \cdot 50 \times 2 \cdot 00 =$ double the Area of Triangle dej or $0 \cdot 30$	
$Af - Ae = ef \times \frac{ej + fk}{2}$ or $1 \cdot 30 \times 2 \cdot 90 =$,, Trapezoid $efkj$,, $0 \cdot 116$	
$AB - Af = fB \times fk$,, $2 \cdot 80 \times 0 \cdot 90 =$,, Triangle Bfk ,, $0 \cdot 252$	
	2) 0·668
	Area, = 0·334

If the Survey has been performed keeping the work to the *left* hand, the offsets to the right of the Chain line, are additive, and those to the left are subtractive from the total area of the figure; if, on the contrary the Survey has been done, keeping the work to the *right* hand, the reverse of the above takes place.

It will then be $1 \cdot 027 - 0 \cdot 334 = 0 \cdot 693$ Acres or 0 Acr. 2 Rds. 31 Per. the balance area of the offsets, to be added or subtracted as the case may be.

In all cases of offsets to a boundary line, the only two figures met with are the triangle and the trapezoid, the former, when the boundary runs from the station point to the first offset, or where the boundary crosses the Chain line; and the latter by each pair of successive offsets, forming the two parallel sides of the trapezoid. The rules for finding the areas of both the triangle and the trapezoid, are given at Pages 63 and 64.

Various are the methods of obtaining contents from the direct measurement of planes and we have in Part. 1. described the method of dividing irregular figures into triangles and trapezia (Page 65,) as well as reducing them to a single triangle (Prob. 12, Pages 71 and 72,) but the chief art in computing, consists in finding the content of pieces of land, bounded by curved or very irregular lines, or in reducing such crooked sides of fields or boundaries to straight lines that shall enclose the same or equal area, with those crooked sides, and so obtain the area of the curved figure by means of the right-lined one, which will commonly be a trapezium. This reducing of the crooked sides to straight ones, is very easy and accurately performed in the following manner:—

Apply the straight edge of a thin, clear piece of lantern-horn or *talc*, to the crooked line, which is to be reduced, in such a manner, that the small parts cut off from the crooked figure by it, may be equal to those which are taken in, which *giving* and *taking* as it is called, can be judged of very nicely by a little practice; then with a fine pointed pencil, draw a line by the straight edge of the horn, and do the same on the other sides of the figure; the straight sided figure thus obtained, will be equal to the curved one, the content of which, will be equal to the content of the crooked figure proposed.

Instead of the straight edge of the horn, a horsehair, or fine thread, may be applied across the crooked sides in the same manner; and the easiest way of using the horsehair, is to string a small slender bow, made of whalebone or thin bam-

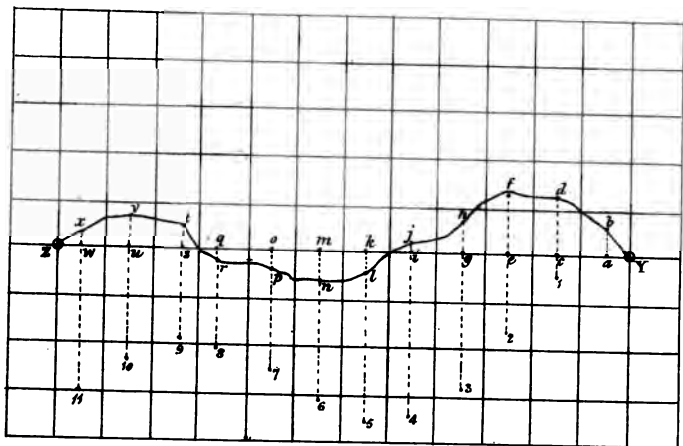
boo with it, for the bow keeping the hair always stretched, it can be easily and neatly applied with one hand, while the other is at liberty to make two marks by the side of it, to draw the straight line by.

We will mention one other method, which for accuracy and despatch of work for small parcels of land, and particularly offsets is far superior to any of those already named.

This consists of a piece of transparent horn or talc, as thin as will admit of strength, divided off into squares of acres and roods; to do which, describe a rectangle, on whatever scale the work is protracted on, of 80 Chains by 72, divide each side into 24 equal parts, and draw lines across joining the divisions, then will each small square be equal to one acre, for 80 Chains multiplied by 72 Chains = 576 acres and the square of 24 is also 576; on one side of the rectangle these squares may be divided off into roods if necessary.

To use this "Talc Square" as it is called, place any of the lines drawn across it, on the Station line of the Survey, in such a manner, that the offsets to the right and left of the line may be all brought within the small squares of the rectangle; then holding the talc firm with the left hand and with a pair of compasses in the right hand, commence at one end of the line and measure the length of such portion of the offset from the Chain line (balancing the irregular edges as near as possible) as may fall within each row of small squares, commencing with the first row on the right, adding this on, by opening out the compasses, to the portion contained in the second row, this again to the portion contained in the third row and so on; if the offset passes to the left of the Chain line, draw in the compasses from the Chain line to the offset, so will the area of offset to the left of the line be deducted; then measure the distance in the compasses along one side of the rectangle, and the number of squares contained within the two legs, will be the area in acres and parts of an acre of the offset.

The following diagram represents a talc square, divided off into acres, placed over the Station line YZ, the crooked line as seen through the talc representing a boundary line.



To calculate the area of the offsets on the line YZ, commence at Z and measure the distance ab , keeping this distance in the compasses, place the upper leg of the compasses at c , and open them *out* to d , place the upper leg again at e , and open them *out* to f , again from g to h , and from i to j , here the offset going to the left of the line, place the upper leg of the compasses on the Chain line at k , and draw them *in* towards l , then at m drawing them in to n , at o , drawing them in to p , and at q to r , the offset again proceeding to the right of the line, the upper leg of the compasses must be placed on s , opening them *out* to t , from u to v and from w to x , then will the number of squares contained within the compasses be the number of acres and parts of an acre contained in the offset on the line YZ.

In the above diagram, the dots on the Chain line, and on the offset, show the measurements to be taken with the upper leg of the compasses and the dots below show where the under

log of the compasses would fall in making the above measurements, observing that the distance from dot 1 to $c = ab$, dot 2 to $e =$ dot 1 to d , dot 3 to $g =$ dot 2 to f , dot 4 to $i =$ dot 3 to h , dot 5 to $k =$ dot 4 to j , and so on to the end of the line.

This instrument can also be used for finding the content of irregular figures of any shape, and is particularly adapted for checking the areas of villages surveyed on the Traverse system, whose area is obtained by a calculation quite independent of a plot as will be hereafter explained.

The best method of making these "Talc Squares" is to draw the rectangle and small squares correctly on a piece of drawing paper or card-board with a fine steel pen, keeping this as a pattern, and whenever a talc square is required, to lay the talc over this, fastening it at the corners with a little gum, to prevent its slipping, and with the point of a pricker to scratch the lines across the talc: when they are all drawn, a mixture of lamp black and oil should be rubbed well into the marks; round the edge of the talc, paste a narrow edging of paper to prevent its breaking.

In connection with the subject of areas or superficial contents, we come to the consideration of an important principle, viz., the reduction of the lines measured over steep slopes to the horizontal plane.

Having to lay down on a plane or flat surface, boundaries and lines at different inclinations, in order to avoid distortion in the out-line, and to bring all the details duly within the framework, it is absolutely necessary that we refer to, or project all lines and points upon a plane. The plane adopted to receive this common projection is the horizontal plane. It is not therefore the actual surface that we have to protract, but the diminished quantity that would result, had the whole been reduced to a horizontal plane.

It is therefore necessary to reduce all sloping or hypothenusal distances to their horizontal lengths. When the lines are long, and the slopes much varied and considerably inclined,

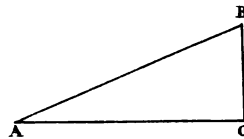
this reduction ought to be made by calculation,* or at least by reference to tables of reduction of hypotenusal lengths to horizontal ones as given below.

TABLE I.						TABLE II.					
Reduction in Links and Decimals upon each Chain's Length, for the following Angles of Elevation and Depression.						Shewing the Rate of Inclination of Inclined Planes, for the following Angles of Elevation.					
Angle.	Re-ductn.	Angle.	Re-ductn.	Angle.	Re-ductn.	Angle.	Onein	Angle.	Onein	Angle.	Onein
3° 0	0.14	9° 0	1.24	15° 0	3.40	0° 15'	228	3° 30'	17	7° 0'	8
		30	1.38	30	3.64	0. 30	114	3. 45	16	7. 30	7½
4° 0	0.25	10° 0	1.52	16° 0	3.88	0. 45	76	4. 0	15	8. 0	7
		30	1.68	30	4.12	1. 0	56	4. 15	14	9. 0	6½
5° 0	0.38	11° 0	1.84	17° 0	4.37	1. 15	46	4. 30	13	10. 0	6
		30	2.01	30	4.63	1. 30	38	4. 45	12	11. 0	5½
6° 0	0.55	12° 0	2.19	18° 0	4.90	1. 45	32	5. 0	11½	12. 0	5½
		30	2.37	30	5.17	2. 0	28	5. 15	11	13. 0	5
7° 0	0.75	13° 0	2.56	19° 0	5.44	2. 15	26	5. 30	10½	14. 0	4½
		30	2.77	30	5.74	2. 30	23	5. 45	10	15. 0	4
8° 0	0.98	14° 0	2.97	20° 0	6.03	2. 45	21	6. 0	9½	16. 0	3½
		30	3.18	30	6.33	3. 0	19	6. 30	9	17. 0	3½
						3. 15	18	6. 45	8½	18. 0	3½

The reduction for one Chain (from the above Table) multiplied by the number of Chains, will give the quantity to be subtracted from the measured length of an inclination, to reduce it to horizontal measure.

Tables of reduction are engraved on the vertical arc of Theodolites which, while they show on one side the angle of elevation or depression, give on the other the number of units per hundred, that have to be deducted to reduce the hypotenusal line to its corresponding horizontal length.

* This calculation is simple : Suppose AC to represent the horizontal plane, and AB the measured line; the angle of elevation BAC being taken with the Theodolite, we have the side AB, the angle BAC, and the angle BCA, a right angle, to find the line AC, which is the horizontal length required.



In small Surveys, especially those made with the Chain only, an allowance or reduction is generally made in the field by construction or estimation as the measurement proceeds. If the slope be not very steep, the reduction is accomplished by holding the lower end of the Chain above the ground, as nearly horizontal as can be judged by the eye, allowing a plummet to hang from the hand that holds the Chain, in order to point, to where the arrow should be placed.

When perfect accuracy, however, is sought, and when the Survey is extensive, the angles of inclination should be observed, and the proper deduction obtained by computation, and allowed for when the work is being plotted.

CHAPTER VI.

ON THE TRAVERSE SYSTEM AND GALE'S METHOD OF SURVEYING.

A TRAVERSE may be defined as a circuitous route performed on leaving any place on the earth's surface, by stages, in different directions, and of various lengths, with a view of arriving at any other place situated in any direction with reference to the former, and at any distance therefrom which cannot be reached in the direction of the shortest line connecting them. The angles which the stages or station lines form with the meridian are called "bearings" the quantity of Northing or Southing made in each *distance*, is called the *difference of latitude*, and the amount of Easting or Westing is termed the *departure*.

When the bearing corresponds with the meridian, or with the perpendicular to it, there will in the former case be no difference of latitude, and in the latter no departure, and the distance measured will itself express the amount of Northing or Southing, or of Easting or Westing due to the change of position.

When, however, the bearing does not correspond with the meridian or with the perpendicular to it, there will be for every distance measured a certain corresponding change both in latitude and longitude (or departure); and as these will with

reference to their particular distance answer the condition of our definition, they may with propriety be termed the *traverses of the distances* :

We will therefore define :

1st. *Meridians* as North and South lines, which are supposed to pass through every station of a Survey, running parallel to each other.*

2nd. The *difference of latitude* or the Northing or Southing of any line, as the distance that one end of a line is North or South from the other end.

3rd. The *departure* of any line, as the perpendicular distance from one end of the line to a meridian passing through the other end.

In the 3rd Cor. Theor. V., (page 12,) it is stated and proved, "that all the interior angles of any rectilineal figure, together with four right angles, are equal to twice as many right angles as the figure has sides" or in other words that—

In any rectilineal figure, the sum of all the interior angles, is equal to twice as many right angles as the figure has sides, less four right angles.

This forms the basis on which the Revenue Survey operations in India are conducted. The Traverse System is a method of computation by rectangular co-ordinates, and is applicable to any mode of surveying, whatever, such as Route Surveys, Railway Lines, Navigation Courses and the like, where every Station is fixed by distances on the meridian and perpendicular, and this is essential to Gale's System, which may be termed the periphery measuring or perimetrical method. By throwing a series of angles over the face of a country, and forming a network of large circuits, the liability of error is reduced within the narrowest limits, which the means at

* These meridians are not really parallel, but converge towards the poles of the earth, but so insensibly as not to be worthy the notice of a Surveyor's operations within a limited space.

disposal permit. This angular Circuit System, in extensive operations in a country like India, with instruments of the best construction and moderate power and size, can alone enable a Surveyor to carry out in practice the theoretical accuracy of the Traverse, and permit by the aid of logarithmic calculation an approximation to the proof required, viz. :

1st. "That the sums of all the interior angles shall be equal to twice as many right angles as the figure has sides, less four right angles" and—

2nd. As regards the linear measurements, "That the sums of the Northings be equal to the sums of the Southings, and the sums of the Eastings be equal to the sums of the Westings, which latter will be presently explained.

It is not intended to be advanced that the Indian System will bear comparison with the Ordnance Survey of Great Britain, as respects the Geometrical principles, on which they are respectively based. The latter is on a Trigonometrical basis throughout, and the errors in detail have never reached the assigned limits of $\frac{1}{300}$ of superficial or $\frac{1}{600}$ of linear measure. The periphery measurement system of India is not capable of giving results so accurate as the Ordnance Survey System, because a space is not rigorously represented by its perimeter, at the same time where *boundaries* are the chief object of the Survey, the simplicity of the latter system, is an immense advantage, and considering the expenditure of time and money the results of the Indian System are admirable. The country could not possibly be surveyed so economically, or so rapidly in any other way, and bearing in mind the relative value of ground in the two countries it would not be advisable to adopt the more expensive and more accurate system of the Ordnance Survey, it would in fact be an endless job in such a vast empire, a complete first Survey likewise, being most urgently needed.

Hutton in speaking of the Traverse Table, observes "that this mode of surveying large tracts of lands was made use of

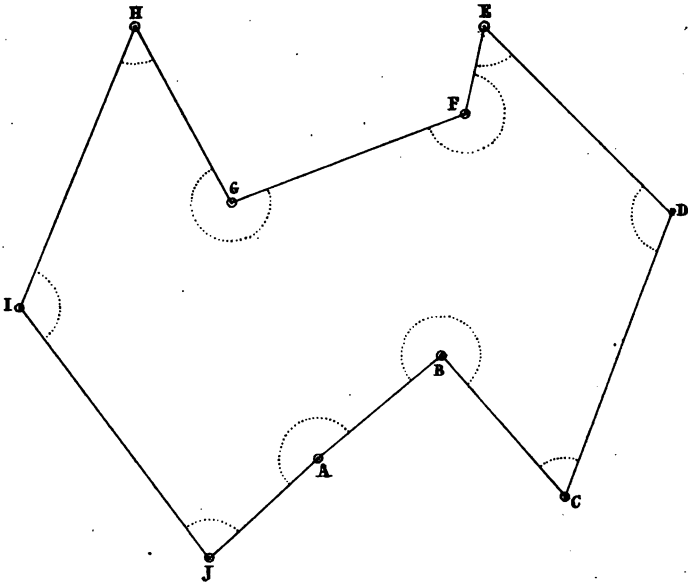
by Mr. Norwood, so far back as 1635, and he adds that in Plotting the Survey of a country thus taken, the Circuit Station lines, though consisting of many hundreds, may be reduced to a few for the first closing, and the like for the intermediates of each line first plotted by which every station may perhaps be more truly placed than by any other method." The above remark is extremely accurate and there is no mode, so efficacious as the one advised. By it can be carried on a Survey methodically and accurately and the operation is wonderfully simplified, which by any other process would be involved in difficulty, error and confusion; and since the meridian and perpendicular columns of the Traverse admit of the Station lines being plotted by mere plain scale and compass, it would be difficult by any other method to effect this part of the work so easily, and by no means could a circuit measurement and its area be made and determined with the precision the Universal Theorem admits of.*

However correctly distances may be measured, unless the angular work is also correct, the result will be unsatisfactory, but with both these data accurately determined, the proof will be certain, and it will be observed, how admirably each step in the work proves the other, and what confidence the system gives to a Surveyor who has no need whatever to put any of his work on paper, but with his Traverse correct, may produce his map at any future period with undoubted certainty.

We will now proceed to explain the mode of Surveying by Traverse.

Draw any figure such as ABCDEFGHIJA, representing the sides of an irregular Polygon.

* Memoranda on the mode of Surveying adopted in the Revenue Surveys, by Major Wroughton, Deputy Surveyor General, in the Agra Printed Selections from public Correspondence, Part 3rd.



If the Theodolite is first set up at the station A, and the interior angle JAB is observed and then at B, observing the interior angle ABC, at C, the interior angle BCD, and so on all round the polygon, then will the sum of all the interior angles, JAB, ABC, BCD, &c., be equal to ten times two right angles (the figure having ten sides) less four right angles or $180^\circ \times 10 - 360^\circ = 1440^\circ$.

In practice it will be found that this result cannot be exactly attained, and that the sum of the angles will generally amount to two or three minutes more or less; to meet this, a correction of one minute in every four or five angles, additive or subtractive as the case may need, is generally necessary to obtain the result required.

Having thus proved the angular work correct, the next operation is to obtain the Bearings of the several sides of the polygon or angles subtended by these sides with the meridian. This is either done by the magnetic needle on the theodolite or by astronomical observation, (the latter will be treated of hereafter in Part V. and various methods given for ascertaining the *true* Bearing of an object) but as all the Revenue Surveys in India progress on the *true* meridian of the earth, we shall therefore treat only of *true* meridional Bearings or angles formed by each line with the *true* meridian. If the Theodolite were adjusted in the plane of the meridian on every station of a Survey, we should find no difficulty in obtaining the true Bearing of each line, but as this would be very troublesome and next to impossible, it is only necessary in practice to obtain the correct Bearing of the first line of a Survey from which by the assistance of the angular work the Bearings of the other lines can be deduced.

This true Bearing being once established has only to be checked and corrected by similar means after every 50 or 100 square miles of country traversed, and it will be found seldom to exceed from 5 to 10 minutes of a degree from the true meridian, whereas, if the magnetic needle was used, an error of 15 or 30 minutes is scarcely traceable in a single observation and where so many instruments are in use, all giving a different magnetic variation, it is plain, that without this method of deducing the azimuths from the angular observations the utmost confusion would arise.

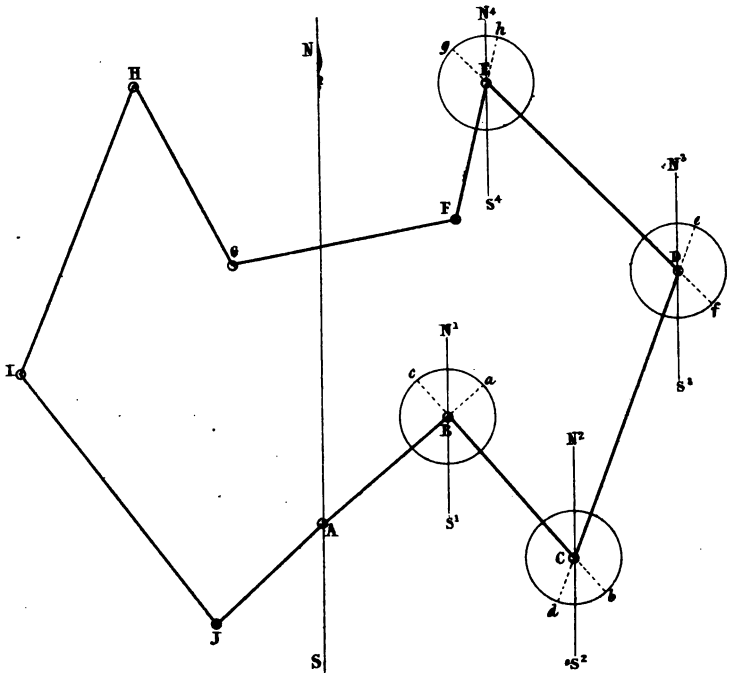
Rule.—To the Bearing of the line preceding that of which the Bearing is sought, add the inward angle formed by these two lines, and the sum increased or diminished by 180° according as it may be less than, or in excess of 180° will be the Bearing of the next line sought.

Before proceeding to prove the above rule, we will first premise, that in all modern Theodolites the divisions are numbered round the circle, from 0° to 360° so that the Bearing of

any object between 0° and 90° is reckoned North-East, between 90° and 180° South-East, between 180° and 270° South-West and between 270° and 360° North-West, 0° , 90° , 180° , 270° , being respectively due North, South, East and West.

This method of reckoning the Bearings of objects is by far the most convenient for practice, as without the necessity of making use of the letters to denote the direction, the Bearing is known at once by the number of degrees contained in the arc.

Let the Bearing of the line AB in the following figure be given, as found by astronomical observation.



To find the bearing of the line BC.—Produce AB to *a*, and CB to *c*.

The two meridians NS, and N'S' being parallel, the angle N'Ba is equal to the angle NAB, if to the angle N'Ba or arc N'a we add the interior angle of the polygon ABC, or its

equivalent in arc $aS'c$, we obtain the angle formed by the line CB with the meridian $N'S'$ or arc $N'aS'c$, if then the angle cBC or 180° be deducted from this, thus reversing the direction of the line, we have left the angle $N'BC$ or Bearing of the line BC with the meridian $N'S'$.

To find the Bearing of the line CD.—Produce BC to b and DC to d .

The two meridians $N'S'$ and N^2S^2 being parallel, the angles $N'BC$ and N^2Cb are equal. If to the angle N^2Cb or arc N^2b , we add the interior angle of the polygon BCD, or its equivalent in arc bS^2d , we obtain the angle formed by the line DC with the meridian N^2S^2 or arc N^2bS^2d , if then the angle dCD or 180° be deducted from this, thus reversing the direction of the line, we have left the angle N^2CD or Bearing of the line CD with the meridian N^2S^2 .

To find the Bearing of the line DE.—Produce CD to e and ED to f .

The two meridians N^2S^2 and N^3S^3 being parallel, the angles N^2CD and N^3De are equal. If to the angle N^3De or arc N^3e we add the interior angle of the polygon CDE, or its equivalent in arc ef , we obtain the angle formed by the line ED with the meridian N^3S^3 or arc N^3ef , if then the angle fDE or 180° be added to this, thus reversing the direction of the line, we obtain the angle N^3DE or Bearing of the line DE with the meridian N^3S^3 .

To find the Bearing of the line EF.—Produce DE to g and FE to h .

The two meridians N^3S^3 and N^4S^4 being parallel, the angles, N^3DE and N^4Eg are equal. If to the angle N^4Eg or arc N^4hS^4g we add the interior angle of the polygon DEF or its equivalent in arc gN^4h , we obtain the angle formed by the line FE with the meridian N^4S^4 or arc $N^4hS^4gN^4h$ from which if we deduct the angle hEF or 180° , thus reversing the direction of the line we have left, the angle N^4EF or Bearing of the line EF with the meridian N^4S^4 .

And so on, this proof may be carried through every line of the polygon, until we come to the last line JA, when its Bearing added to the interior angle JAB \pm or $- 180^\circ$ as the case may require will give the original starting Bearing of the line AB.

We have been thus prolix in explaining how the Bearings of the above four lines of the polygon are obtained, as they contain cases in each quadrant of the circle, BC, being a South-East Bearing, CD, North-East, DE, North-West, and EF, South-West; the same rule is however applicable to the remaining sides.*

* If the sum of the preceding Bearing and forward angle after deducting 180° amounts to more than 360° , deduct 360° from the total, the remainder will be the Bearing of the next line.

CHAPTER VII.

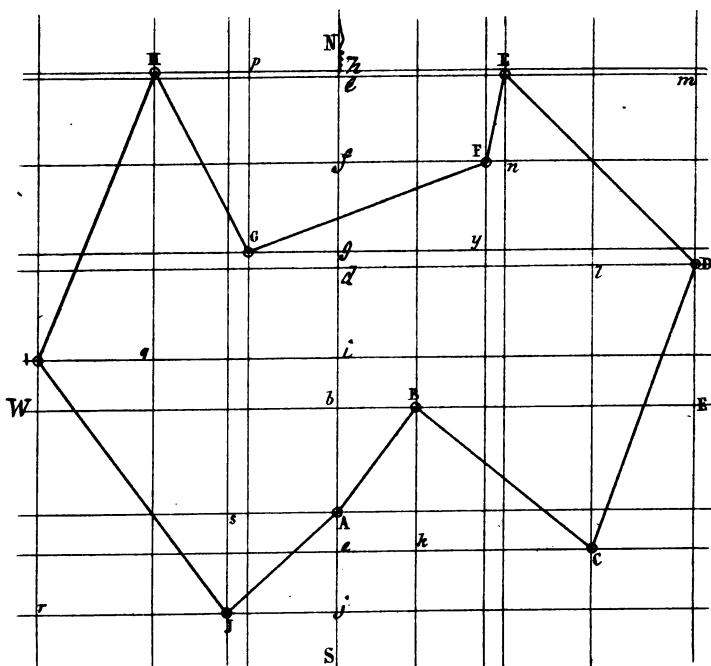
ON THE PROOF OF THE TRAVERSE, AMOUNT OF ERROR ALLOWED, AND METHOD OF CORRECTION.

WE now offer for consideration the following Theorem, viz. :

That in every Survey, correctly taken, the sum of the distances gone North from a certain point, will be equal to the sum of the distances returned South to the same point, and that the sum of the distances gone East, will be equal to the sum of the distances returned West.

The truth of the above is self-evident, for the meridians within the limits of an ordinary Survey having no sensible difference from parallelism, it must necessarily follow, that if a person travel any way soever within such limits, and at length come round to the place where he set out, he must have travelled as far to the North as to the South, and to the East as to the West, though the practical Surveyor will always find it difficult to make his work close with this perfect degree of exactness.

We will however explain this more fully with the assistance of a diagram.



Let the line NS run due North and South, and EW due East and West. If we fix on the point A, as a starting point and a person walks from A to b , on the line NS, say 400 yards, and wishes to return to A, he must walk back 400 yards; in going therefore from A to b , and back from b to A, he has walked 400 yards North and returned 400 yards South. In the same manner if he fixes on the point b as a starting point, and walks to B on the line EW say 300 yards to get back to b , he must return 300 yards; in walking therefore to B, he has gone 300 yards East, and returned 300 yards West.

Supposing now, he walks from A to B, say 500 yards in the direction of the line AB, he will then have gone North from A, 400 yards, and East from A, 300 yards.

In a continuation of the figure, having walked or measured from A to B, he proceeds on and measures from B to C, in doing so, he goes a certain distance South and a certain distance

East of B to arrive at C, thence he measures to D, going a certain distance North and East of C to arrive at D, from D he measures to E, from E to F, and so on, going North, South, East or West, from the preceding station as the direction of the line may be, until he arrives back at his original starting point, A. In making this tour therefore, he has gone the same distance North as he has returned South, and the same distance East as he has returned West.

Let the vertical and horizontal lines drawn through the several stations A, B, C, &c., represent, the former, a series of meridians or North and South lines or lines of longitude and the latter, a series of East and West lines or lines of latitude; as these lines of latitude and longitude are all respectively perpendicular and parallel to each other, it follows that the angle formed by the intersection of the meridian line of one station, and the latitudinal line of the next station as at *b*, *k*, *l*, *m*, &c., must be a right angle or 90° .

Now supposing all the lines AB, BC, &c., to have been carefully measured with a Chain, and that having obtained the Bearing of the line AB, by astronomical observation, we have deduced the Bearings of all the other lines by the rule, (page 277); we then have the data in each line, of a side and two angles to find the other two sides.

For instance, in the triangle *A**b**B*, we have the side AB, and the two angles *b*AB, *A*bB, (the latter being invariably 90° or a right angle) to find the other two sides *A*b and *b*B the former being the difference of latitude, and the latter the departure of the station B from A. In like manner, in the triangle *B**k**C*, we have the side BC, and the two angles *C*B*k*, (obtained by deducting *N*BC from 180°) and *B*k*C* (a right angle) to find the other two sides *B*k and *C*k, the former being again the difference of latitude and the latter the departure of the station C from B, and so on for every line round the figure.

The object of calculating all the sides of these several right-angled triangles on each line, is to obtain the difference of

latitude and departure of each station from the preceding one, which difference being found, the sums of all differences of latitude of lines going North must equal the sums of all differences of latitude of lines going South, or

$$Ab + Cl + Dm + Gp + Js = Bk + En + Fy + Hq + Ir$$

and the sums of all differences of departure of lines going East, must equal the sums of all differences of departure of lines going West, or

$$bB + kC + lD + rJ + sA = mE + nF + yG + pH + qI$$

and if this is not the result of the above calculations, the Survey has not been truly taken.

We have before stated, that in the measurement of angles, a certain correction is allowed in practice, to obtain the result of the Theorem, which forms the basis of the work, so also in the measurement of Chain lines, a correction is necessary to meet the errors, that notwithstanding the greatest care will occur. In actual practice the columns of latitude and departure will not balance exactly, for inaccuracies must arise from observations and chaining in the field, which no care could obviate. To adjust these differences, previous to defining the meridian distances, the rule is, that should the discrepancy amount to $\frac{1}{2}$ of a Pole or 5 Links for every station, it will be clear an error has been made in the field measurements, which must be discovered by a re-survey. When differences, however, are within these limits, the amount of error allowed is 1 Link in 10 Chains, additive or subtractive from the sums of the Northings and Southings to correct the latitude, and from the sums of the Eastings and Westings to correct the departure.

This error must be apportioned among each of the distances of the Survey by the following proportions, viz :

As the sum of all the distances is to the whole error, so is each distance to its correction.

This must be done for the latitudes and also for the departures, and is entered in a column appropriated to each, called the North and South correction, and the East and West correc-

It will be observed that the sum of the several corrections as above apportioned amounts to .14 in the Northings and Southings or $.095 + .045 = .14$ and to .28 in the Eastings and Westings or $.124 + .156 = .28$. This is the method of subdividing an error in theory, but in practice an approximation is sufficient, the proportion of error to each line being made without reference to calculation, the error when it is below the maximum allowed, of 1 Link in 10 Chains being equally divided between the two columns of Northings and Southings and of Eastings and Westings, and generally thrown into the longest lines. The example given however must not be understood as a specimen of the real extent of correction on such small distances, we have taken ample figures merely to serve the purpose of illustration.

We have omitted mentioning here the several methods given in other works on "Surveying by the Traverse system" of finding unknown distances, by adding up the Northings and Southings, and the Eastings and Westings of a Polygon, and applying the difference of the two severally, as the latitude and departure of the unknown line and thence finding the Chain distance. Polygonometry as given in Hutton's mathematics Vol. 3, and other books, treat of these methods, and to which we refer the reader for further information.

CHAPTER VIII.

ON THE METHOD OF PLOTTING BY TRAVERSE.

THESE differences of latitude and departure, or distances on the meridian and perpendicular of each station from the preceding one are not only applicable to the proof of the field-work, but are subservient also to the plotting and computation of the area of the Survey, which will now be explained.

All the distances on the meridian of each station from the preceding one, North or South, and all the departures of each station from the preceding one, East or West, can be referred to the meridian of the first station or starting point of the Survey, viz., station A. For instance, on the meridian of A, for the line AB the distance North is Ab and the departure East is bB ; on the meridian of B, for the line BC, the distance South is Bk , and the departure East is kC ; deduct the distance that B is North of A, from the distance that C is South of B, and we obtain the distance that C is South of A, or $Bk - Ab = Ac$; in like manner add the distance that C is East of B, to the distance that B is East of A, and we obtain the distance that C is East of the meridian of A, or $kC + bB = cC$.

Again, on the meridian of C for the line CD, the distance North is Cl , and the departure East is lD , deduct the distance that C is South of A, from the distance that D is North of C, and we obtain the distance that D is North of A, or $Cl - Ac = Ad$; in like manner add the distance that D is East of C, to the distance that C is East of A, and we obtain the distance that D is East of the meridian of A, or $lD + cC = dD$.

On the meridian of D, for the line DE, the distance North is Dm and the departure West is mE , add the distance that E is North of D to the distance that D is North of A, and we obtain the distance that E is North of A, or $Dm + Ad = Ae$; also, deduct the distance that E is West of D from the distance that D is East of A, and we obtain the distance that E is East of A or $dD - mE = eE$, and so on all round the figure until arrived back at A, when the distance that A is North of J, the preceding station, deducted from the distance that J is South of A, or $Aj - Js$, and the distance that A is East of J, deducted from the distance that J is West of A, or $jJ - sA$ will leave no remainder, proving that the calculation has been correctly made.

The line FG it will be perceived crosses the meridian of A, in this case, it is only necessary to deduct the distance that F is East of A from the distance that G is West of F, to obtain the distance that G is West of A or $yG - fx = gG$.

To plot therefore all these station points, draw a meridian line, and another perpendicular to it, representing the East and West direction. Fix on any point on this meridian line for the station A, lay off with a pair of common compasses and a scale of equal parts the distance Ab North of A, draw a line parallel to the East and West line through the point b , lay off the distance bB , East, and join the points A and B, we thus obtain the bearing and distance of the line AB.

Next lay off the distance Ac South of A, draw a line parallel to the East and West line, through the point c , lay off the distance cC East, and join the points B and C, thus obtaining the bearing and distance of the line BC.

Then lay off the distance Ad North of A, and with a parallel to the East and West line through the point d , lay off the distance dD East, join C and D, and we obtain the bearing and distance of the line CD, and so on all round the figure, observing that when the distances on the perpendicular are West of the meridian of A or starting point, they are laid

off West on the plot. The reduction of the distances on the meridian and perpendicular of each station to the first station or starting point is therefore easily effected by a simple addition or subtraction, and may be comprised in the following rule.

Rule.—When the distances run North of the first station, add them one to another, until they change to South, then deduct them one by one until the Southing exceeds the Northing, when deduct the latter from the former, changing the denomination to South; all distances then going South, are added and those going North deducted, and so on, until arrived back at the original starting point.

Likewise in the distances on the perpendicular, when the distances run East of the meridian of the first station, add them one by one until they change to West, then deduct them until the Westing exceeds the Easting, when deduct the latter from the former changing the denomination to West; all distances then going West are added, and those going East deducted, and so on, until arrived back at the original starting point.

This method of plotting is by far the most perfect, and the least liable to error of any that has been contrived; it may appear to require more labour, than the common method by angular protraction or protraction by Bearings, on account of the computations required, but these are made with so much ease and expedition by the help of Traverse Tables,* that this objection would vanish, even if they were of no other use than for plotting, but as we have already said, they are subservient also to finding the Area, and which cannot be ascertained with

* A set of Traverse Tables has been published by Major J. T. Boileau, Bengal Engineers, to every minute and degree of the quadrant, and these Tables are now in general use in the Revenue Surveys; we therefore refer the Surveyor to this work, in which he will find the method of using them fully explained and much valuable information regarding the application of the system to general purposes.

equal accuracy in any other way; when this is considered, it will be found to be attended with less labour on the whole than the common method.

One great advantage in the above method of plotting is, that if a station is incorrectly plotted, it does not affect in the least, the correctness of the other stations, which is not the case when plotting with a common protractor by Bearings or angles, where an error made in plotting one line is carried on through the series.

CHAPTER IX.

ON THE UNIVERSAL THEOREM.

WE must now look on the distances on the perpendicular above computed of each station from the first in the series or starting point, as the sides of certain figures which multiplied into the distances on the meridian between each station, will give certain products, from which the area of the figure is derived by an easy computation from the following :

UNIVERSAL THEOREM.

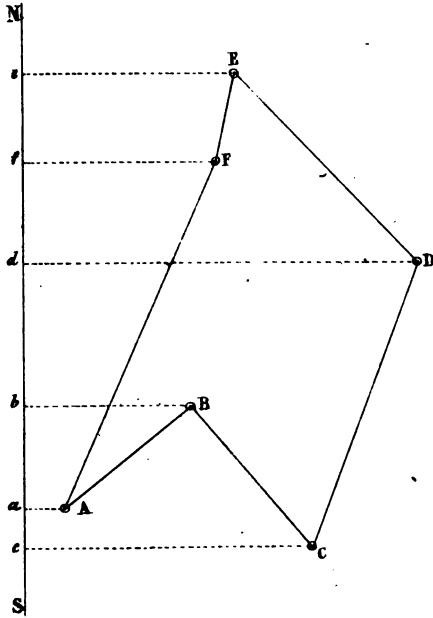
If the sum of the distances of an EAST and WEST line of the two ends of each line of a Survey, from any meridian lying entirely out of, or running through the Survey, be multiplied by the NORTHING or SOUTHING made on each respective line; the difference between the sum of the NORTH PRODUCTS and the sum of the SOUTH PRODUCTS, will be double the area of the Survey.

To explain this Theorem, it is necessary to take the three different cases that present themselves separately, which are—

1st. When the meridian is to the West of the polygon and lying entirely out of the Survey.

2nd. When the meridian is to the East of the polygon and lying entirely out of the Survey.

3rd. When the meridian runs through the polygon a portion of the Survey lying East and West of it.



CASE 1ST.

When the meridian is to the West of the polygon and lying entirely out of the Survey.

Let ABCDEFA be any polygon, NS an indefinite straight or meridian line.

Draw perpendiculars aA , bB , cC , dD , eE , fF , from the extremities of each side of the polygon, meeting the line NS, at a , b , c , d , e , f , then will the distances ab , bc , cd , de , ef , fa , be the co-sines of the inclinations of the sides AB, BC, CD, DE, EF, FA, with the line NS.

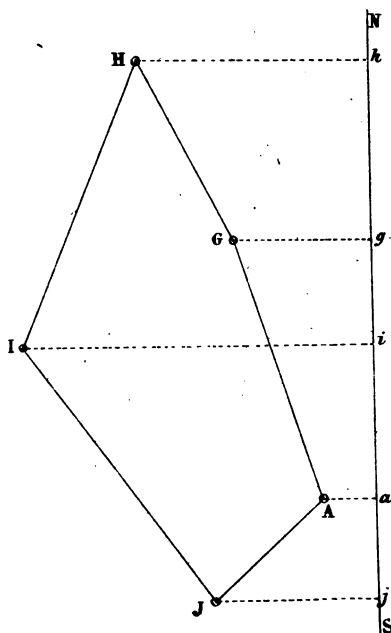
If therefore we multiply the sum of the perpendiculars at the extremities of each Northing or ascending side of the polygon by the co-sines of the inclinations of their respective sides with the line NS, and place them in one column, calling them North Products, and if we multiply the sums of the perpen-

diculars at the extremities of each Southing or descending side of the polygon, by the co-sines of the inclinations of their respective sides with the line NS, and place them in another column, calling them South Products, then will the sum of the *South* Products deducted from the sum of the *North* Products be double the area of the polygon, that is:

$(\overline{aA + bB \times ab + cC + dD \times cd + dD + eE \times de}) -$
 $(\overline{bB + cC \times bc + eE + fF \times ef + fF + aA \times fa,})$ will
 be double the area of ABCDEFA.

For, the sum of the North Products will be double the area of $cCDEec + aABb$, and the sum of the South Products will be double the area of $cCBAFEec + aABb$.

But it is evident, from an inspection of the figure, that $cCDEec - cCBAFEec = ABCDEFA$. If therefore the area of $aABb$, which is common to the North and South Products be struck out, we have left $cCDEec - cCBAFEec = ABCDEFA$, and consequently the difference of their doubles must be equal to double the area of ABCDEFA.



CASE 2ND.

When the meridian is to the East of the polygon and lying entirely out of the Survey.

Let AGHIJA (Page 293) be any polygon, NS an indefinite straight or meridian line.

Draw perpendiculars aA , gG , hH , iI , jJ , from the extremities of each side of the polygon meeting the line NS, at a , g , h , i , j , then will the distances, ag , gh , hi , ij , ja , be the co-sines of the inclinations of the sides AG, GH, HI, IJ, JA, with the line NS.

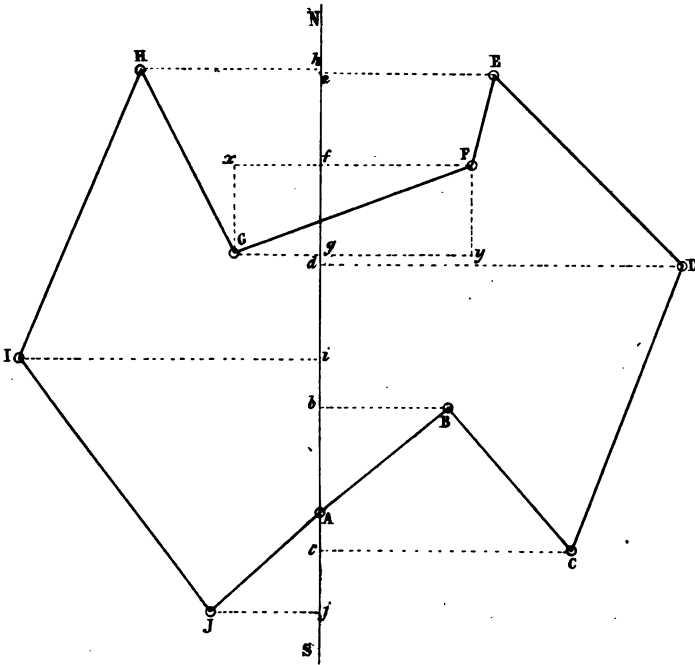
If we multiply the sums of the perpendiculars at the extremities of each Northing or ascending side, by the co-sines of the inclinations of their respective sides with the line NS, and place them in one column, calling them North Products, and if we do the same with each Southing or descending side, and place them in another column calling them South Products, then will the sum of the *North* Products deducted from the sum of the *South* Products be double the area of the polygon, that is :

$$(\overline{hH + iI \times hi} + \overline{iI + jJ \times ij}) - (\overline{jJ + aA \times ja} + \overline{aA + gG \times ag} + \overline{gG + hH \times gh,})$$

will be double the area of AGHIJA.

For the sum of the North Products will be double the area of $jhHG AJj$ and the sum of the South Products will be double the area of $jhHLj$.

But, it is evident from an inspection of the figure, that $jhHLj - jhHG AJj = AGHIJA$, and consequently the difference of their doubles must be double the area of AGHIJA.



—

CASE 3RD.

When the meridian runs through the polygon.

The above figure is a junction of the two last under a common meridian NS, passing through the point A, and consequently *through* the polygon.

To obtain the area of this polygon, in the same manner as in the last two cases, it is necessary to have a set of North and South products, for that portion of the polygon lying to the East of the meridian line NS, another set for the portion lying West of the meridian, and again a third calculation for the line FG, which lying partly to the East and partly to the West of the meridian, its two portions must be separately calculated.

It will be observed that the only difference between the 1st and 2nd cases is, that in the former, of the polygon lying to the *East* of the meridian, the *South* products are deducted from the *North* products, to obtain double the area, and in the latter, of the polygon lying to the *West* of the meridian, the reverse takes place, viz.: the *North* products are deducted from the *South* products to obtain double the area of the polygon; this would be equally necessary in this polygon, but in practice instead of having two sets of North and South products, one set for the portion of a polygon, lying East of a meridian line, and another set for the portion lying West (in cases such as this where the meridian line runs *through* the polygon) it is usual to reverse the products of that portion of the polygon to the West of the meridian line, and enter them in the same columns as the products of the portion of the polygon to the East of the meridian line, *i. e.*, that all products of sides running *North*, to the West of the meridian are placed in the column of *South* products and *vice versa*, all products of sides running *South* to the West of the meridian are placed in the column of *North* products.

Two columns are thus sufficient, for if in the 1st case, the South products deducted from the North products give double the area to the East of the meridian, and in the 2nd case, the North products deducted from the South products give double the area to the West of the meridian, and the North products and South products of the 2nd case, are changed and applied as South products and North products in the 1st case, or *vice versa*, we shall obtain the same result, as if we had two sets of North and South products.

It only remains therefore to explain, how the area is obtained of that portion of the polygon lying East and West of the meridian or on the line FG.

Produce Ff to x and Gg to y and draw Gx and yF parallel to NS .

It is evident, from an inspection of the figure, that if the area of the rectangle $Ffgy$ to the East of the meridian be found, and placed in the column of South products it being a Southing or descending side, and the area of the rectangle $fxGg$, be found and placed in its column of South products, it being also a Southing or descending side to the West of the meridian, (supposing us to have two sets of North and South products) and we reverse the latter and place it in the column of North products in the Traverse Table, the line FG will have a North and a South product too, one product being the area *West* of the meridian, the other the area *East* of the meridian, but to facilitate calculation and simplify the work, it is better to deduct the lesser product from the greater, and carry the difference to the column in which the excess is. The same result, however, is obtained by taking the difference between the perpendiculars East and West of the two points, and multiplying it by the co-sine of inclination of the line, placing the product in its proper column North or South, as the case may be, in the present instance, it is

$gy \times Fy =$	Area of $Ffgy$	or South Product	to the East	of the Meridian	
and $gG \times Gx =$	,, $fxGg$,,	,,	,,	,, West	,,
	or reversed ,,	North Product	,,	East	,,

The difference of the two would be carried to the South products, the excess being South, we should obtain the same result however, if we take the difference between yg and gG and multiply by Fy , which is the usual method in the Traverse Table.

Having now explained why these products are called North and South products, and also shown that the difference between them gives double the area of the polygon, we will exemplify how they are obtained by a reference to the diagram page (295.)

We have already said, that to obtain the area, we must look on the distances on the perpendicular as computed from the first station or starting point, as the sides of certain figures

which multiplied into the distances on the meridian, will give the North and South products above alluded to, for instance :

On the line AB, the distance on the perpendicular bB , multiplied into the distance on the meridian Ab , will give double the area of the triangle ABb a North product, the line AB running Northward.

On the line BC, the sum of the distances on the perpendicular at each end, or $bB + cC$ multiplied into the distance on the meridian bc , will give double the area of the Trapezoid $bcCB$, a South product, the line BC, running Southward.

On the line CD, the sum of the distances on the perpendicular at each end or $cC + dD$ multiplied into the distance on the meridian cd will give double the area of the Trapezoid $dcCD$, a North product, the line CD running Northward, and so on, until we arrive at the last product on the line JA.

The North and South products being then respectively added up, the difference between the two sums will be double the area of the Survey, the half of which will give the area in acres and decimal parts of an acre.

We may here observe that in all the works in which the Universal Theorem has been treated of, for the ascertainment of areas, the meridian has been assumed as lying entirely out of the Survey, but this is contrary to practice. The meridian of a village circuit must naturally pass through the first station of a Survey, at the point where the instrument is first set up and except in very peculiar figures, this causes a portion of the figure to fall on *both sides* of the meridian.

To *assume* a meridian to pass entirely out of the Survey, it is necessary to go out of our way, and from its extreme Easting or Westing to adopt a quantity greater than either, and so calculate the length of each co-ordinate from this assumed distance, at the same time that it involves the necessity of an extra calculation for finding the area. There is no possible advantage in this method, as the same result is obtained by making use of the co-ordinates East and West of a meridian

running through the Survey, giving considerably less figures in the calculation and consequently less labour in deducing the products.

To follow therefore the simplest and most natural course as met with in daily practice, must be the most advantageous and it is not only so as regards the area, but likewise in respect to the plotting; to take the meridian passing through the first station, the protraction is at once easily and simply laid down, without the necessity of further calculation and more inconvenient lengths of scale and compass.

An assumed meridian out of the Survey is still more at variance with systematic precision and progress, whereas in extended operations many villages are plotted on the same sheet of paper, and where each circuit must be built on its own meridian passing through the first station. On the Indian Revenue Surveys, therefore, the shorter and more practical method is pursued and when it is considered that from 1500 to 2000 circuits are on an average annually surveyed by each party employed, a faint idea may be gleaned of the labour saved by the improvement above specified.

CHAPTER X.

ON THE TRAVERSE TABLE.

HAVING in the last few Chapters given an explanation of the Traverse System of surveying from its commencement, viz : the angular work and measurements in the field, to the finding the area of the land surveyed, it only remains to simplify the process, which has taken some pages for explanation, by embodying the whole in a table for the purpose and calculating the polygon given in page (295). In the adjoining table

Col. No.	1	contains the letters representing the stations of the Survey.
„	2	„ the angles as observed in the Field.
„	3	„ the corrections made in those angles, to prove them by Cor. 3, Theo. V., Page 12.
„	4	„ the bearings of the several lines deduced as per Rule Page 277.
„	5	„ the distances as measured in the Field.
„	6, 7	„ the distance on the meridian between every two stations.
„	8, 9	„ the departure of each station from the meridian of the preceding one.
„	<i>a, a, a, a</i>	„ the corrections applied to each calculation, to prove the Survey correct as per Rule Page 284.
„	10	„ the distances on the meridian of each station from the first in the series.
„	11	„ the departure of each station from the first in the series.
„	12	„ the sums of each pair of co-ordinates obtained from Column 11, to be multiplied into Columns 6 and 7, when the respective products are placed in Columns 13 and 14.

TRAVERSE TABLE.

Stations.	Angles as taken in the Field.	Correction.	Bearings deduced from Angles.	Distances as measured in the Field.			Distances on Meridian.			Distances on Perpendicular.			Distances on the meridian of each station from the first station in the series.	Distances on the perpendicular of each station from the first station in the series.	Sums of the perpendiculars on the perpendicular as co-ordinates for multipliers.	North Products in Acres.	South Products in Acres.	
				Chs. Lks.	Chs. Lks.	Chs. Lks.	North.	South.	Correction.	East.	West.	Correction.						
A	270 11	..	50 12	8 35	5 33	-01	..	..	..	..	..	..	N 5 33	E 6 42	E 6 42	3 42	..
B	61 10	..	140 23	9 70	..	..	7 47	..	..	..	..	S 2 14	12 60	19 02	..	..	..
C	118 41	1	21 33	15 98	14 84	..	..	..	..	..	..	N 22 49	18 46	31 06	..	46 08	..
D	56 42	..	315 14	13 80	9 79	-01	..	..	..	..	..	22 49	8 76	27 22	..	26 63	..
E	237 01	..	191 56	4 52	..	..	4 42	..	..	..	..	18 07	7 83	16 59	..	..	..
F	264 21	..	248 57	13 05	..	..	4 69	-01	..	..	..	13 38	4 36	3 47	..	..	..
G	49 40	..	333 18	10 58	9 45	..	..	..	..	..	..	23 83	9 10	W 13 46	..	..	..
H	121 03	1	202 58	16 10	..	..	14 83	-01	..	..	..	8 00	15 38	24 48	..	36 29	..
I	83 18	..	144 01	16 42	..	..	13 23	..	..	..	..	5 28	5 75	21 13	..	28 06	..
J	182 53	..	47 19	7 81	5 28	-01	..	..	..	..	..	0 00	0 00	..	..	..	..
A	1440 00	2	50 12	..	44 69	08	44 69	02
10	1440 00	2	50 12	..	44 69	08	44 69	02

Proof of Angles 10 X 180 — 360 = 1440.

Difference,..... 101 58

Half, 50 79 Acres.

Area of Offsets, + 3 80

54 59 or 54 Ac. 2 Rds. 14 Per.

The following simplification of the method of calculating columns 4, 6, 7, 8, 9, 10, 11, 12, 13 and 14 will, it is hoped, place the matter beyond doubt; and by comparing each given quantity with the diagrams, the mode of obtaining its corresponding result will be easily understood.

To obtain Column 4 of the Table from Column 2.

Given the Bearing of the line AB, $50^{\circ} 12' N. E.$ as found by Astronomical observation, or otherwise. (Diagram Page 278.)

Then,

Bearg.	AB	$50^{\circ} 12'$	+	$\angle B$	$270^{\circ} 11'$	$= 320^{\circ} 23'$	$- 180^{\circ} = 140^{\circ} 23'$	S. E.	or Bearg.	BC		
„	BC	140	23	+	„	C	61	$10 = 201$	$33 - 180 = 21$	33 N. E.	„	CD
„	CD	21	33	+	„	D	113	$41 = 135$	$14 + 180 = 315$	14 N. W.	„	DE
„	DE	315	14	+	„	E	56	$42 = 371$	$56 - 180 = 191$	56 S. W.	„	EF
„	EF	191	56	+	„	F	237	$01 = 428$	$57 - 180 = 248$	57 S. W.	„	FG
„	FG	248	57	+	„	G	264	$21 = 513$	$18 - 180 = 333$	18 N. W.	„	GH
„	GH	333	18	+	„	H	49	$40 = 382$	$58 - 180 = 202$	58 S. W.	„	HI
„	HI	202	58	+	„	I	121	$03 = 324$	$01 - 180 = 144$	01 S. E.	„	I J
„	IJ	144	01	+	„	J	83	$18 = 227$	$19 - 180 = 47$	19 N. E.	„	J A
„	JA	47	19	+	„	A	182	$53 = 230$	$12 - 180 = 50$	12 N. E.	„	A B

To obtain Columns 6, 7, 8 and 9.

Rule.—As Radius : Distance :: Cosine of Bearing : Latitude and :: Sine of Bearing : Longitude or Departure.

Latitude = Distance \times Cos. Bearing; or

Departure = Distance \times Sin. Bearing.

(See Diagram Page 282.)

Line	AB	Lat.	A	$b = AB$	Cos.	A	Long.	b	B	$= AB$	Sine	A
„	BC	„	B	$h = BC$	„	B	„	h	C	$= BC$	„	B
„	CD	„	C	$l = CD$	„	C	„	l	D	$= CD$	„	C
„	DE	„	D	$m = DE$	„	D	„	m	E	$= DE$	„	D
„	EF	„	E	$n = EF$	„	E	„	n	F	$= EF$	„	E
„	FG	„	F	$y = FG$	„	F	„	y	G	$= FG$	„	F
„	GH	„	G	$p = GH$	„	G	„	p	H	$= GH$	„	G
„	HI	„	H	$q = HI$	„	H	„	q	I	$= HI$	„	H
„	IJ	„	I	$r = IJ$	„	I	„	r	J	$= IJ$	„	I
„	JA	„	J	$s = JA$	„	J	„	s	A	$= JA$	„	J

Example of Columns 6, 7, 8 and 9.

On the Line AB given, Bearing N. E. 50° 12' Distance 8.35

	<i>Cosine.</i>	<i>Sine.</i>
Bearing 50°12'	9·806254	9·885621
Distance 8·35	0·921686	0·921686
	<hr/>	<hr/>
	·727940 = 5·35 Lat.	·807207 = 6·41 Dep.

The above example by Major Boileau's Tables, (see Note Page 289.)

	<i>Latitude.</i>	<i>Departure.</i>
Bearing 50°12'	5·12 800 6·15	
	·19 30 ·23	
Distance 8·35	·04 5 ·08	
	<hr/>	<hr/>
	5·35	6·41

To obtain Column 10 from Columns 6 and 7.

Line AB	Dist. on Merd.	of A to B or Ab	= N 5·33	
" BC	"	" B ,, C ,, Bk	= S 7·47	
			<hr/>	
			S 2·14	Diff. { Distance on Meridian
" CD	"	" C ,, D ,, Ct	= N 14·84	{ of A to C or Ac
			<hr/>	
			N 12·70	" { " " "
" DE	"	" D ,, E ,, Dm	= N 9·79	{ of A to D or Ad
			<hr/>	
			N 22·49	Sum, { " " "
" EF	"	" E ,, F ,, En	= S 4·42	{ of A to E or Ae
			<hr/>	
			N 18·07	Diff. { " " "
" FG	"	" F ,, G ,, Fy	= S 4·69	{ of A to F or Af
			<hr/>	
			N 13·38	" { " " "
" GH	"	" G ,, H ,, Gp	= N 9·45	{ of A to G or Ag
			<hr/>	
			N 22·83	Sum, { " " "
" HI	"	" H ,, I ,, Hq	= S 14·83	{ of A to H or Ah
			<hr/>	
			N 8·00	Diff. { " " "
" IJ	"	" I ,, J ,, Ir	= S 13·28	{ of A to I or Ai
			<hr/>	
			S 5·28	" { " " "
" JA	"	" J ,, A ,, Js	= N 5·28	{ of A to J or Aj
			<hr/>	
			0·00	

To obtain Column 11 from Columns 8 and 9.

Line AB	Departure of A to B or	$bB = E$	6:42		
" BC	" " B " C "	$kC = E$	6:18		
		<u>E 12:60</u>		Sum = Dep. of A to C or	cC
" CD	" " C " D "	$lD = E$	5:86		
		<u>E 18:46</u>		" " " A " D "	dD
" DE	" " D " E "	$mE = W$	9:70		
		<u>E 8:76</u>	Diff.	" " " A " E "	eE
" EF	" " E " F "	$nF = W$	0:93		
		<u>E 7:83</u>		" " " A " F "	fF
" FG	" " F " G "	$gG = W$	12:19		
		<u>W 4:36</u>		" " " A " G "	gG
" GH	" " G " H "	$pH = W$	4:74		
		<u>W 9:10</u>	Sum	" " " A " H "	hH
" HI	" " H " I "	$qI = W$	6:28		
		<u>W 15:38</u>		" " " A " I "	iI
" IJ	" " I " J "	$rJ = E$	9:63		
		<u>W 5:75</u>	Diff.	" " " A " J "	jJ
" JA	" " J " A "	$sA = E$	5:75		
		<u>0:00</u>			

To obtain Column 12 from Column 11.

Line AB	Departure of A to B or	$bB = E$	6:42		
Line BC {	" " A " B "	$bB = E$	6:42		
	" " A " C "	$cC = E$	12:60		
		<u>E 19:02</u>		Sum of Co-ordinates.	
Line CD {	" " A " C "	$cC = E$	12:60		
	" " A " D "	$dD = E$	18:46		
		<u>E 31:06</u>	" "		
Line DE {	" " A " D "	$dD = E$	18:46		
	" " A " E "	$eE = E$	8:76		
		<u>E 27:22</u>	" "		
Line EF {	" " A " E "	$eE = E$	8:76		
	" " A " F "	$fF = E$	7:83		
		<u>E 16:59</u>	" "		
Line FG {	" " A " F "	$fF = E$	7:83		
	" " A " G "	$gG = W$	4:36		
		<u>E 3:47</u>	Diff.	" "	

Line GH	{	Departure of A to G or $gG = W$	4·36
		„ „ A „ H „ $hH = W$	9·10
		<u>W 13·46</u>	Sum of Co-ordinates.
„ HI	{	„ „ A „ H „ $hH = W$	9·10
		„ „ A „ I „ $iI = W$	15·38
		<u>W 24·48</u>	„ „
„ IJ	{	„ „ A „ I „ $iI = W$	15·38
		„ „ A „ J „ $jJ = W$	5·75
		<u>W 21·13</u>	„ „
„ JA		„ „ A „ J „ $jJ = W$	5·75

*To obtain Columns 13 and 14, from the multiplication of
Column 12 into Columns 6 and 7.*

		North Prod. N. E. & S. W.	South Prod. N. W. & S. E.
Line AB	$bB \times bA$ or N 6·42 × E	5·33 =	3·42
„ BC	$bB + cC \times bc$ „ S 19·02 × E	7·47 =	14·20
„ CD	$cC + dD \times cd$ „ N 31·06 × E	14·84 =	46·08
„ DE	$dD + eE \times de$ „ N 27·22 × E	9·79 =	26·63
„ EF	$eE + fF \times ef$ „ S 16·59 × E	4·42 =	7·33
„ FG*	$fF - gG \times fg$ „ S 3·47 × E	4·69 =	1·63
„ GH	$gG + hH \times gh$ „ N 13·46 × W	9·45 =	12·71
„ HI	$hH + iI \times hi$ „ S 24·48 × W	14·83 =	36·20
„ IJ	$iI + jJ \times ij$ „ S 21·13 × W	13·28 =	28·06
„ JA	$jJ \times jA$ „ N 5·75 × W	5·28 =	3·03
	Sums ..	<u>140·48</u>	<u>38·90</u>
		38·90	

Diff. .. 101·58 Acres = double
the area of ABCDEFGHIJA.

Consequently

$$\begin{aligned} & (bB \times bA + cC + dD \times cd + dD + eE \times de + hH + iI \times hi + iI + jJ \times ij) - \\ & (bB + cC \times bc + eE + fF \times ef + fF - gG \times fg + gG + hH \times gh + jJ \times jA) \\ & = \text{Double the area of the figure ABCDEFGHIJA, Page 295.} \end{aligned}$$

* The Co-ordinates here changing from East to West, or crossing the Meridian of Station A, the *difference* between the pairs instead of the *sum* is taken, by which means the area of the Parallelogram $Fx Gy$, is properly balanced, the portion lying to the West of the Meridian of A, being cancelled by a portion on the East side, leaving a difference in favor of the latter, and which accordingly remaining East and multiplied by a Southing, forms a South Product.

*

We have now endeavoured to explain the Traverse Table, and though all the operations which have been given at length for the sake of explanation appear laborious, they are performed with the greatest facility, the whole with the exception of Columns 6, 7, 8 and 9, being obtained by a simple addition or subtraction, and Columns 13 and 14 by multiplication. Such is the traverse system of surveying, and to use Mr. Adams* words "the superior accuracy and ease with which every part of the process is performed, cannot, it is imagined, fail to recommend it to every practitioner." To apply the system in practice will form the subject of other Chapters.

* Geometrical Essays by George Adams, 1813.

CHAPTER XI.

ON THE STRENGTH OF A REVENUE SURVEY ESTABLISHMENT, AND DETAILED DUTIES OF ITS COMPONENT PARTS.

THE Establishment of a Revenue Survey is regulated according to circumstances and the requirements of the Government, but in general they are confined to two grades, a *double* and a *single* establishment. In the North-Western Provinces, where the completion of the settlement was deemed of great importance, the strength under each Officer was of the former character and consisted of the following persons, viz. :

Revenue Surveyor,	1
Covenanted Assistant,	1
Sub-Assistants,	7
Native Assistants or Mootsuddies,	25 to 30
Tindals, Classies, or Measurers,	170 to 200
Khusrah, fixed Establishment,	6
Guard,	16 to 25

And for which a fixed annual maximum sum was granted under the four leading heads, viz. :

	Rs.
Surveyor and Contingencies, @ 726	8,712
Assistants,	13,680
Native Establishment,*	13,980
Field Guard,	1,152
Total per Annum,	37,524

* Includes one Native Doctor now attached to all Surveys.

The several parties which have been brought into Behar and Bengal and are now employed, have been kept up to this strength, but those which have been appointed for Bengal alone, have been invariably of the *single* strength, viz. :

Revenue Surveyor,	1
Sub-Assistants,	4
Native Assistants or Mootsuddies, ...	20
Tindals, Classies, or Measurers,	120 to 150
Khusrah, fixed Establishment,	4
Field Guard,	4 to 8

And for which the following is the annual maximum grant sanctioned by Government viz. :

	Rs.
Surveyor and Contingencies, @ 626	7,512
Assistants,	10,800
Native Establishment,*	13,260
Guard,	304

Total per Annum, 31,876

Within this sum therefore the Surveyor is permitted to adapt his Establishment to the emergencies of his work and the seasons of the year. During the active period for field operations, generally averaging 7 months in the year, a full complement of Classies are kept up, and the monthly expenditure may be in excess, of what the total sum divided by 12 would yield, but this is balanced by extensive reductions during the recess months; the great body of the Classies are then discharged, and others put on half-pay, and for this reason an annual, instead of a monthly maximum, is sanctioned; this is, likewise controlled by the head of the department whose audit of the monthly bills is essential before they are passed on to the Civil Auditor.

* Includes one Native Doctor now attached to all Surveys.

The usual salaries of Assistants and Sub-Assistants are as follows:

Assistant Surveyor, in charge,	388
Assistant Surveyor,	250 to 350
Senior Sub-Assistant,	200
Sub-Assistant, 2nd Class,	150 to 175
Sub-Assistant, 3rd Class,	100 to 125
Sub-Assistant, 4th Class,	75 to 100

And the general time of service required to entitle Assistants to the higher grades is,

After 25 years' service,	Rs. 350	per mensem.
20 " "	" 300	"
15 " "	" 250	"
10 " "	" 200	"

At the general conference at Allahabad in 1833, of all the old Officers employed in the department, which was likewise attended by Lord William Bentinck, the Governor General of India, it was agreed upon that with the *single* establishment, which up to that period had never been increased, an area of 1,000 square miles of topographical Mouzawar survey per season could be effected, provided the average size of the villages was $1\frac{1}{4}$ square miles, or 800 acres, and by a systematic arrangement of the various duties of each person employed, this quantity of work has generally been got through under even less favorable circumstances than villages of a square mile average. In 1837, the Sudder Board of Revenue, N. W. P., brought forward the new scheme of the double establishments, with a view of exacting 3,000 square miles per annum, but although this enormous extent of work has been approximated, by several of the old North-West Surveyors, it has been rarely attained, and in the complicated districts of Bengal, with small villages of scarcely more than *half* a square mile each, cannot possibly be either expected, or (with reference to general accuracy) be desired.

The general duties of a survey establishment are divided into two grand heads, viz., Field and Recess. The Field season is supposed to commence in October, and continue until the 1st June, though in Bengal, it is difficult to commence active operations before the 15th of November, at the earliest. During this period, the sole object is to prosecute the survey operations to the best advantage, devoting only such time to the elements of the computations, as tend to leave no doubt as to the accuracy and entire confidence in the Field observations and measurements. The remainder of the year from June to November, when camp life must be exchanged for cantonments during the periodical return of the rainy season, the full attention and zealous industry of every individual is demanded in perfecting the maps, registers, and innumerable calculations, and although the nature of the Field and Recess business differs materially, yet it is difficult to say which is the most trying and irksome; generally speaking perhaps, the Field is preferable to the office duty.

On commencing active operations the survey establishment is divided into as many separate working parties as the strength will permit; generally from three to four independent camps or divisions are formed, each being placed under the charge of a competent European or East Indian Assistant, with such proportion of chain or surveying parties as the means available admit of. A Senior Sub-Assistant should be competent to superintend and systematically work 4 Boundary Assistants and 3 Interior or Geographical detail Surveyors, and such a party will be able to survey about 120 villages, or from 60 to 70 square miles per month.

The Sub-Assistant conducts the survey of the main or Pergunnah circuit, observes the angles and records them with the distances of the station lines in the Field-book; it is his duty to arrange the whole of the smaller or village circuits for the Native Sub-Assistants and to examine and compute the data furnished by these boundary Surveyors, to protract the work

and see if the offsets have been properly taken, and to check the azimuth extending from village circuit to circuit, and make it accord with the true azimuth of the main circuit at every point at which a junction is proved. He must regulate likewise the filling-in, of the Geographical details of every village circuit, and guard against any error in the proceedings of the native Surveyors who perform this duty, taking especial care that the magnetic variation of the compass used for this purpose is properly adjusted to the true meridian and the bearings laid down on the Field map accordingly. It is the duty of this Officer also to compare the external boundary of the village map with the *Thákbust* or Settlement Officer's demarcation map, and to make an immediate report of any discrepancies which may appear, and when the measuring Aumeens are engaged in the Sub-Assistant's Division he has to test their work in the Field, and control and check any abuses which may come to his knowledge; he has likewise to render an account of the progress of the survey, and to see that a due amount of daily Field-work is produced by each chain party under him, and he is strictly responsible for the accuracy of every portion of the work within his own division, which must be duly attested, before it is sent on to the Superintending Officer.

The Native Sub-Assistant in charge of a Boundary party surveys all the village circuits, within the main or Pergunnah circuit, observes the angles with the Theodolite, keeps the Boundary Field-book in English and enters the offsets. On the close of each day's Field labor, or as soon as a convenient quantity of work is completed, he forwards the Field-book to the Sub-Assistant, who extracts all the data for making, or as it is termed *putting up*, the traverse. The Boundary Surveyor also immediately reports any difference he may have observed between the *Tháks* or mud pillars and other marks actually existing in the Field, and the sketch map furnished by the Settlement Officer.

The interior detail Native Sub-Assistant surveys all the Geographical details within each village circuit with a Prismatic or common surveying compass and chain, such as the village sites, rivers, nullahs, jheels, roads, temples, &c., sketching in large tracts of jungle or waste, and recording the *Mofussil* name of each village site. Being furnished with a drawing board and T square with the exterior lines of the village circuits protracted thereon, the boundary on any particular line can easily be re-surveyed by this individual or any disputed piece of land laid down according to the decision of the local authorities. The interior Native surveyor also is available for collecting statistical information from the village authorities and zemindars such as the number of houses, ploughs, head of cattle, the soil, crops and harvest; and in cases where the Khusrah Aumeens do not extend their measurements to such villages, this plan may be followed with advantage, although it may be the means of delaying the detail survey a little.

A Boundary chain party consists of the following individuals, whose special duties will be remarked on in the sequel :

Native Assistant Surveyor.....	1
Tindal	1
Chainmen.....	3
Flag-footers	4
Offset-man	1
Instrument carrier	1
	—
Total.....	11

This number is absolutely required for the effective prosecution of the survey, in addition there is generally a Police Burkundauze or Peadah from the Settlement Officer attached, to cause the attendance of the parties concerned on both sides of the boundary, and to prevent complaints and demands for *Russud* or supplies. The interior chain party requires only

8 men, which is ample for the nature of the survey and the instruments employed.

The duty of the Revenue Surveyor is to exercise a general superintendence over the whole establishment, and to direct the combined Professional and Khusrah operations in such a manner that accuracy and despatch may be preserved, and at the same time that neither should be unduly sacrificed to the other, he must regulate his progress so as to keep his expenditure within the maximum allowed sum. On him devolves the chief and most important point of laying down the true meridian by Astronomical observation, and of testing the same in various parts of his work, and thus satisfying himself that the azimuth conveyed from main circuit to main circuit does not deviate from its true inclination beyond the allowed error. He should be constantly on the move visiting each Sub-Assistant's camp, rendering advice and assistance in cases of difficulty, and examining into the state of the work as it progresses step by step, taking especial care that the calculations to the extent of the *proof* items are fully brought up and keep pace with the Field-work. He should have a thorough knowledge of his district, and be thus able to check any glaring defect in the delineation of the Geographical features of the country; in fact, as the responsible agent, it should be the aim of this Officer to maintain such a systematic and methodical course, that his own, and all his subordinates professional character may be secured.

Another great and important point in the duty of the Surveyor, as well as his Assistants, is to keep all the instruments in a proper and efficient state, and on all occasions to see that they are in perfect adjustment. The most liberal supply of the very first rate instruments is granted by the Government, and as the wear and tear on a Revenue survey is very great, too much attention cannot be paid to the subject. With such a proportion of Native agency, it may be imagined that a Theodolite employed daily for six months in the year, subject

to all weathers, must suffer in some measure and unless looked after will soon get out of order. On the character and capability of his instruments, the value of a Surveyor's labors must in a great degree depend. It is therefore essential that as often as the occasion demands, a Theodolite should be carefully cleaned; the limb should be dusted with a fine camel hair brush, and periodically on the close of a Field-season, the graduated silver limb should be gently washed with soap and water, and then cleaned with a piece of old silk, some fine olive oil and a little lamp black, freshly made and free from grit—the best oil for the axis is goose or duck fat. All instruments damaged, or worn out, and requiring repair are sent to Calcutta during the recess, and put into efficient working order, or exchanged in the Mathematical Instrument Maker's Department, and returned in time for the ensuing season's work.

In addition to a full complement of Classies or Measurers for each Sub-Assistant and Native Surveyor a considerable number of men of the same class, are required for preparing the station lines preparatory to survey; this preliminary duty is most important, and requires much time and skill in its efficient performance, and without all the stations are so marked out ready for the survey party, the valuable time of the Sub-Assistant would be lost, and an undue cost thus thrown on the work; frequently there is a vast deal of jungle to be cut through, occupying a line-cutting party several weeks; distinct sets of men are told off, for the main circuit and the village circuits.

Main Circuit Line-cutters are employed in preparing the station points of a survey on the exterior of a Pergunnah or other tract of country, and their method of proceeding is as follows:

The Tindal, (selected from the most expert and intelligent of the Classies) is accompanied by a Classie, sometimes two, and receiving his orders to start from a given point on the exterior of a Pergunnah, generally where three Per-

gunnahs meet, plants his first station at the tri-junction; he does this by means of a bamboo peg, about a foot long, which he drives firmly into the ground, leaving about 2 inches of it above the surface and round which he cuts 5 trenches, as shown in Fig. 1, Plate V; these station points are called *Pergunnah Triple-boundary Stations*; this done, he stands over the peg, holding a flag upright, and directs his Classie to proceed on along the boundary of the Pergunnah, until he comes to a spot where three villages meet, he there plants another peg and marks it as shown in Fig. 2, Plate V; these points are called *Village Triple-boundary Stations*.

Should the offsets to the boundary between these two station points be too great, or exceed 5 chains on each side of the line, (which can easily be ascertained by the direction of the bamboo marks or mud pillars erected to mark the boundary line, and which is invariably done, previous to the survey commencing,) intermediate station points must be planted in such a manner that the offsets on each line may be brought within the above limit, all these intermediate stations are marked as shown in Fig. 3, Plate V.

To enable the Tindal to ascertain the names of the villages, &c., to his right and left hand as he proceeds and to ensure his keeping on the boundary of the Pergunnah, he is furnished with a general Perwannah, on the different Zemindars, to give such information and assistance as may be necessary. The Tindal proceeds in this manner, running a series of stations all round the Pergunnah, keeping it to his left hand, marking where the exterior Pergunnah changes by cutting 5 trenches, every village triple-boundary by 3 trenches, and every intermediate station by 2 trenches, until he arrives back at the point he started from; near each station, a bamboo with a wisp of straw is generally planted in the ground, to enable the Assistant when surveying the main circuit, as this is called, to see the direction of every succeeding station, and thus prevent any delay in finding them when in the Field.

The duties of the *Village Line-cutter* are exactly similar to those of the main circuit line-cutter with this exception, that, whereas the main circuit line-cutter does his work by main or large circuits of Pergunnahs, the village line-cutter does his by smaller circuits of villages, contained *within* the main circuit, making use of all the triple-boundary stations of the former, on the main circuit, as so many points for closing his own work on; he proceeds thus:

He takes any village triple-boundary station on the main circuit as a starting point, and keeping the village to his left hand, he sends his Classie forward along the boundary, until he comes to a spot where 3 villages of the Pergunnah meet, including the one he is preparing the stations of, he there plants a station cutting the trenches as in Fig. 2, Plate V., and filling up between the two points with other stations should the offsets on each side exceed 5 chains.

Thence the Classie proceeds along the boundary, still keeping the same village to his left hand, until he comes to another triple-boundary, marking it and filling up intermediately as above, he continues on until he arrives on the main circuit again, at a different station from where he commenced, here he closes his work on the main circuit station, as all the stations between his closing one, and the one he started from have been already prepared by the main circuit line-cutter.

Having thus completed the stations for one village, he commences again on either a triple-boundary of his own work just prepared, or again on a main circuit triple-boundary, and keeping the village to his left hand, he proceeds round it, until he comes upon a main circuit triple-boundary, or one of his own interior village triple-boundaries, where he again closes his work, as the intermediate stations, between where he started, and where he has just closed, if the main circuit have been prepared by the main circuit line-cutter, and if of interior village circuits, they have been prepared by himself; he thus proceeds with every village within the Pergunnah

until the whole of them are prepared in the manner described.

Should the Pergunnah be large, consisting of 150 or 200 villages, it is usual to send 3 or 4 parties, to prepare the village stations, subdividing the Pergunnah equally amongst them, and starting them from opposite sides, in such a manner, that they may all meet at the closing of their work, when no confusion will take place, in their taking one another's stations to close on.

Main circuits can also be subdivided in the same manner, by starting the line cutters from various Pergunnah triple-boundary points, on the exterior of the Pergunnah, and directing them to proceed on, keeping the Pergunnah to their left hand, until they come to the next Pergunnah triple-boundary, when if another line-cutter has started from thence, he will find it out, by seeing the station point already prepared, and on which he must close his portion of the main circuit.

Village line-cutters are always supplied with a list of villages within the Pergunnah of which they have to prepare the stations, and they are furnished with a Perwannah, on the various Zemindars within their track, to obtain such assistance and information as may be necessary to prosecute their work.

Line-cutters' duties are very troublesome and laborious, for they act as pioneers and prepare the country for survey, and have many difficulties to overcome, not only from the nature of the country, but from the delays caused by the non-attendance of village authorities, and the difficulty of procuring the information they require to enable them to carry on their work; they are generally in consequence paid a higher rate than the Classies, or from 5 to 6 Rupees per mensem.

Chainmen are employed in measuring the distances between the station points as above prepared by the line-cutters; two men drag the chain, and a third is necessary to hammer the pin in and stand by it until the rear man comes up, this

leaves a durable mark on the ground, and precludes a chance of miscalculation, should the arrow be disturbed by the chain—for the method of measuring chain lines and keeping the accounts of them see page 103.

Offset-men. Their duty is to measure the offsets from the chain line to the boundary, and for which purpose they are provided with an offset rod of 20 links in length, generally made of a light bamboo—directions for its use and of the cross staff will be found at page 104.

Flagmen are supplied with light bamboos, about 20 feet in length, and shod with an iron spike (Fig. 4, Plate V.,) surmounted by a small triangular black or red and white flag, (Fig. 5, Plate V.,) according to the fancy of the Surveyor; these bamboos are held perfectly upright on the several station points, prepared by the line-cutters, and on them the surveyor fixes the cross-wires of his Theodolite to obtain his angular observation.

Plummets are sometimes used, attached to the bamboos, to ensure their being held quite perpendicular, but they are troublesome and inconvenient; it is quite sufficient for the flagman to place the iron spike of the bamboo on the centre of the bamboo peg at the station point, keeping the latter between his feet and holding the bamboo with both hands about the height of his chest, and in a line with his nose (Fig. 6, Plate V.,) his front being turned towards the Surveyor.

Three flagmen are sufficient for one Theodolite, but with a practised and expert Surveyor *four* are necessary to prevent delay; their method of proceeding is as follows:

The Surveyor having fixed his Theodolite on his starting station point, sends one man to the back station, and one to the forward station, keeping the third with himself, or at the station where his Theodolite is planted; having taken his angular observation, by any of the methods shown at page 132, the flagman standing by him, waves his flag to the right and left, when the man at the back station, understanding this

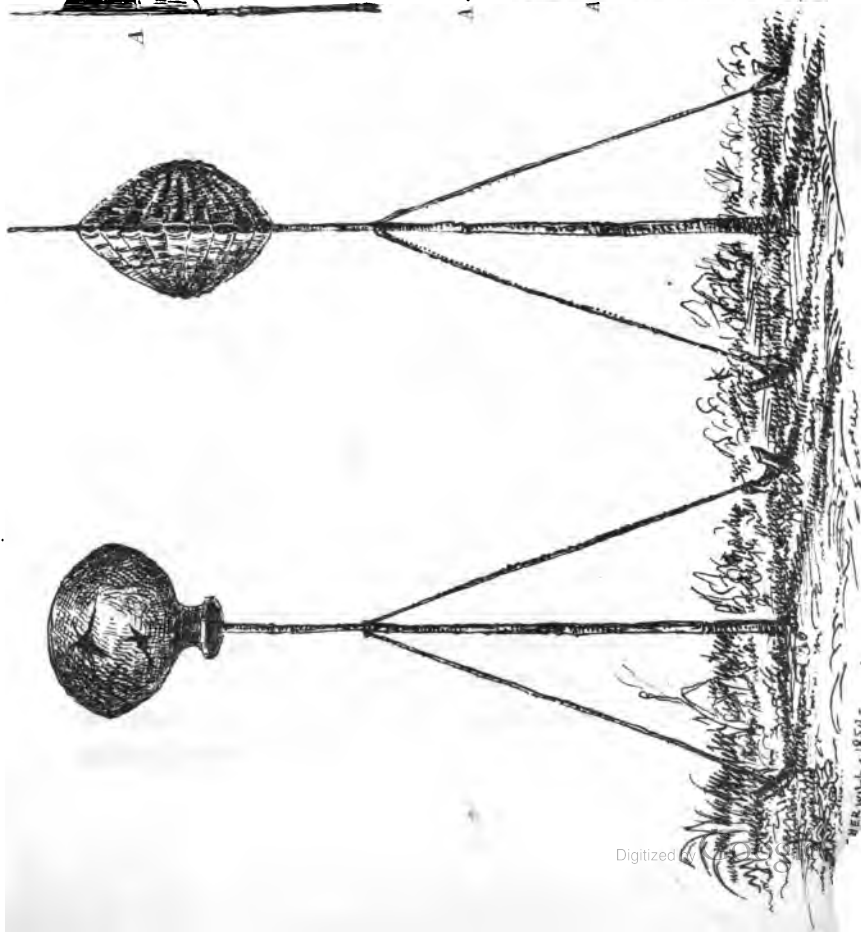


Fig. 1.

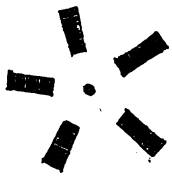


Fig. 2.



Fig. 3.



Fig. 4.

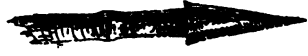


Fig. 5.

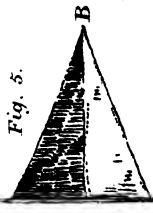
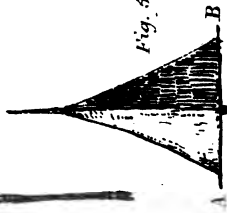


Fig. 5.



B



Fig. 5.

A. B. Pieces of Bearnboo to keep the
 Flag extended, when there is
 no wind.

as his signal, comes up to the station where the Theodolite was and relieves the flagman there, who runs on and relieves the flagman at the forward station, who in his turn proceeds on to the next station.

All these reliefs are made whilst the Surveyor is engaged measuring the distance between the two station points, so that on his arrival at the end of the chain line, the flagmen are again in their proper position, to enable him to observe his second angle, and thus no time is lost.

The flagmen thus continue on from station to station, relieving one another, until the circuit of the village is completed. Flagmen should be light, smart, and active men, and well trained to running, for much time is sometimes lost by the Surveyor in having to wait for the forward flagman reaching his station.

Instrument carriers, are for the purpose of carrying the Theodolite or compass from station to station. They are supplied with a leather sling belt, (Fig. 7, Plate V.,) ending in a socket, into which the feet of the Theodolite stand, when closed up, are introduced; this sling belt bears the weight of the instrument, and should therefore be made of sufficient strength for the purpose, the instrument is kept steady and upright by holding it as shown in the figure.

Instrument carriers or Theodolite men, as they are generally called, should be selected from the strongest and most careful of the Classies, for it is no easy matter to carry a Theodolite about all day fixed on its tripod stand.

The instrument box is strapped over the shoulders, like a knapsack, and is slung, so that the Theodolite is always carried in an upright position (Fig. 8, Plate V.) These boxes being exposed to the sun the greater part of the day, should be well protected with a cloth cover wadded with cotton; a five or six inch Theodolite can be carried about the whole day by one man, but a 7 inch requires two men to relieve one another.

These men should be taught to carry the instrument, so as not to jerk it by the motion of the body and to be careful in avoiding going under trees, as very often a stray branch is liable to knock the instrument off its stand, for which reason a Surveyor should be careful after every observation to see that the spring clamp which retains the instrument on its tripod (as described in page 129,) is secure.

The remaining Classes are employed in carrying the T square and board, the Cross-staff, &c., their duties requiring no particular notice.

CHAPTER XII.

ON THE COMMENCEMENT AND EFFECTIVE PROSECUTION OF A REVENUE SURVEY.

ON the proper division of labor depends the successful progress of a Survey; duties once told off, should be adhered to for the season's operations; if a Surveyor is continually changing the duties of his establishment, he will as surely get his work into confusion, and delays and consequent check will be the result. Some system or method must be observed in disposing of a large establishment to the best advantage, and by a judicious distribution of the proportion of European to the Native establishment, and suitable localities of the Head-Quarters of each camp or party, the allowed means are turned to the best account.

It must not, however, be supposed that every Officer superintending a Survey, observes the precise same system of carrying out the details of his work.

The profession of a Surveyor above all others affords the most ample scope for ingenuity of practice, and it will generally be found that every Surveyor has peculiar methods of various practical sorts by which he believes his operations are benefitted; we shall therefore endeavour to explain in the following pages, the leading principles of our own experience combined with the knowledge of that of several contemporaries.

On the Revenue Surveys in India, the Surveyor is not merely dependant on his own resources, he has to look to the

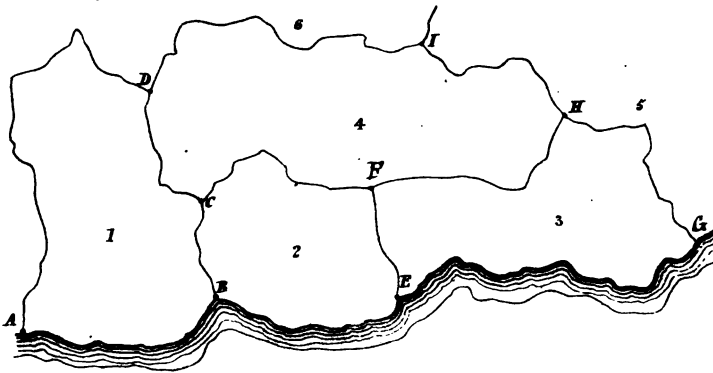
proceedings of another and distinct establishment, that of the Civil or Settlement Officer, to be supplied with a sufficient quantity of work, and without the proper adjustment and preparation of boundaries by this functionary, no Survey can proceed. This is explained at length under Part IV. of this Book, treating of the important division of all Revenue proceedings the *Khusrah* or Native Field measurement.

In the first place, it is advisable to obtain, if possible, a map or sketch of the district coming under Survey, and by getting a bird's eye view of the country, to decide where the Surveyor should commence, and how and in what direction he ought to proceed so as to keep his work compact; he must settle at once the spot where his first meridian line is to be laid down and note the different localities where he will test his meridian as he proceeds.

Some months previous to taking the Field, he will communicate with the Settlement Officer, and make all necessary arrangements with him for the progress of the combined operations of both Professional and *Khusrah* Survey. The *Pergunnahs* or other divisions to be surveyed during the season, must be decided on, as well as that portion of each *Pergunnah*, on which the Survey operations are to commence, the number of *Thâkbusts* of villages or demarcation papers required monthly must be settled, as well as the number of villages requiring measurement by *Khusrah*. All preliminaries must be arranged prior to taking the Field, and there should be such an understanding between the Surveyor and Settlement Officer, as may prevent all hindrance to the progress of the work; the object of *both* should be to co-operate mutually with each other, and so overcome all difficulties that may present themselves.

The season's work being thus, as it were, set in order, about a month previous to the establishment taking the Field, the main circuit line-cutters are sent out, to prepare the stations of the main circuits as shown in the last chapter.

These men receive their orders from and are under the immediate control of the Revenue Surveyor, who should direct them in their duties, and on no account should they be interfered with by the Assistants or others on the establishment. For the better elucidation of the manner of commencing a Survey, we will suppose the tract of country represented in



the annexed sketch, to be a portion of the work allotted to an establishment for the season, and the different divisions, numbered 1, 2, 3, 4, &c., to consist of certain Pergunnahs or other local subdivisions within the district to be surveyed, the river to the south of the whole forming the boundary of the district in that direction.

Our first object is to enclose these several Pergunnahs or subdivisions within a number of station lines, with a view of obtaining a correct series of angular observations and chain measurements round the exterior of each, and which is termed a *Main* circuit, the correctness of which being ascertained by the usual proof by traverse, the errors of all the minor or *Village* circuits surveyed within the main circuit are prevented from extending themselves beyond. The traverse calculations of a main circuit are never altered when once proved, and they are, together with the angles, bearings and distances, all applicable to the several village circuits in which the main circuit lines may fall.

To prepare a circuit therefore of the kind, the main circuit line-cutters receive their orders as follows :

One line-cutting party to start from A, a second to start from B, a third from E, a fourth from H, and a fifth from D.

The first party starting from A, are directed to proceed along the northern bank of the river, keeping Pergunnah No. 1 to their left hand, until they come on No. 2, then to run their lines between Nos. 1 and 2, as far as No. 4, to continue on between Nos. 1 and 4, up to No. 6, or the point D, from whence the fifth party abovementioned started, and to close the work on the Station D previously made.

The second party starting from B, are directed to proceed along the northern bank of the river, keeping Pergunnah No. 2 to the left hand, and arriving at No. 3, to run lines between Nos. 2 and 3, touching No. 4, continuing on between Nos. 2 and 4, until they come on No. 1, or the Station C, made by the *first* party as they progressed on the main circuit of No. 1, closing on the same station.

The third party starting from E, are directed also to proceed along the northern bank of the river towards circuit No. 5, then to run their lines between Nos. 3 and 5, until they come on No. 4, continuing the Stations between Nos. 3 and 4, in the direction of No. 2, closing work on the station at F, made by the *second* party, as they progressed with the main circuit of No. 2.

The fourth party starting from H, are directed to proceed along the boundary of No. 4, keeping it to the left hand, noting the Station I, in the usual manner, as the triple-boundary of Nos. 4, 5 and 6, and to continue on to station D, or the point whence the *fifth* party commenced their portion of the main circuit of No. 1, and to close work on that station.

The fifth party starting from D, are directed to keep No. 1 to their left hand, and proceed on until they arrive at the starting point A, from whence the *first* party commenced

work, noting the triple-boundaries of Nos. 1, 6 and 7, in their progress.

These five line-cutting parties starting their work simultaneously, it is necessary, that they should take up the triple-boundary stations common to each other as closing points for their respective work; for instance, the second party starting from B, at the same time that the first starts from A, it is necessary that the latter should take up Station B in their work, as they progress round towards C and D, the same as regards the second and third party, the former should take up Station E in their work, and so on for all of them; if they neglected doing this, there would be two stations at every Pergunnah triple-boundary, which would cause much confusion in the work.

In the absence of a map of the district, some difficulty may be experienced in directing the line-cutters at first, but the Revenue Surveyor should endeavour, by all practicable means, to obtain a knowledge of his district, either by information obtained from Zemindars or others, or what is better, to take a ride over it in different directions and especially over the parts where his work is to commence, and obtain information for himself; when once the four or five first Pergunnahs of a district are got over, they of themselves show much of the boundaries of the adjoining ones, and a morning's ride or two in advance of his work together with the assistance of one or two smart Tindals, sent about to obtain information, will soon enlighten him as to how the general disposition of the next adjoining Pergunnahs run.

In the above manner, four main circuits enclosing an area from 3 to 400 square miles are prepared at one and the same time, and they should be surveyed in the same way, *i. e.* one Assistant should start from A, and run the circuit ABCDFA, a second should start at B, and run the circuit BEFC, closing his work on C, a third should start at E, and run the circuit EGHF, closing his work on F, and a fourth should start at H, and run the circuit HID, closing

his work on D, and if the Assistants are at all expert, supposing the number of stations to average 180 per main circuit, the whole should be completed within a week. The angular observations and chain distances between two adjoining main circuits are made common to both, by reversing the angles and measurements of one circuit, which are then applicable to the adjoining one, or in other words, that the angles observed and distances measured from B to C, in No. 1 circuit, by being reversed,* will answer for the angles and distances from C to B, in No. 2 circuit, and that the angles and distances from C to D, in No. 1, reversed, will furnish the angles and distances from D to C, in No. 4, and so on through all the circuits. By these means each circuit is made complete, and adopts itself to the usual proof, bringing the Survey round from the station whence it started, to the same point of departure again, and thus the difference of latitude and departure of each triple-boundary is identical in both contiguous circuits.

To prevent the possibility of error in the chain lines it is an excellent plan and one that is generally adopted for the Assistant to have a Native Surveyor following in his track, carrying on a second measurement of the lines in his rear as he proceeds, which re-measurements should be compared every evening as soon as the Native Surveyor arrives at the station where the Assistant has closed work for the day, and any discrepancy appearing, it should be corrected the first thing the next morning by a third measurement.

It is not necessary for an Assistant surveying a main circuit to take the offsets to the boundary marks, as it would cause much delay to his progress; they can be taken up by the Native Surveyor when surveying the villages in which the several lines on the main circuit fall.

As soon as the Assistant completes the survey of a main circuit he should forward his Field-book of the angles and dis-

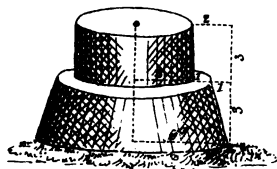
* By reversing an angle is meant deducting it from 360° .

tances at once to the Revenue Surveyor, whose duty it is, to put up, calculate, and correct each circuit; this may be considered by some Surveyors as the duty of the Assistants, but they have ample work with the village circuit survey to occupy the whole of their time, without being taxed with these calculations, and as the correctness of the general work depends entirely upon these main circuits, the Superintending Officer is the proper person to look to them.

When these Field-books are sent in by the Assistant, the main circuit line-cutters should immediately be told off to prepare other circuits, so that they may have them ready for survey by the time the village circuits are completed within the circuits just closed.

Whilst the main circuits are being surveyed, the Revenue Surveyor should be employing himself in fixing his meridian line, that a correct azimuth for the work may be ready by the time the several Assistants close their circuits, for on the correctness of this azimuth rests the entire basis of the work.

The first station to be selected for the survey, viz., A, should be the point where the boundaries of three Pergunnahs meet; this forming a point of departure for the whole survey from which the co-ordinate distances of all remarkable places and conspicuous objects are calculated, must be made *permanent* by building over it a circular brickwork pillar about 6 feet diameter, as in the adjoining diagram, the station being the centre from which the circle for the pillar is described; this pillar serves also as a good landmark from which the boundary of the three congregated Pergunnahs may easily be traced, and from which point, the true azimuth of all surrounding conspicuous objects, such as a mosque, temple, remarkable tree, village, &c., must be observed, a full description of the same being given in the



records of the Survey with a view of easily identifying the station again, and leading off therefrom the true meridian.

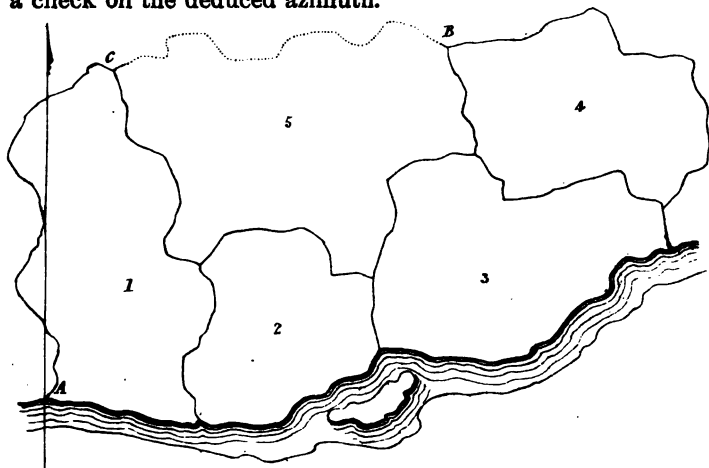
On this station, A, the Theodolite must be firmly placed,* to ascertain by any of the methods, as shown in Part V. of this work, the true azimuth of the first line of the survey. The Surveyor should not, however, rest satisfied with the azimuth of his first line being correct; for unless the angular observations between two given points, which in a distance of 10 miles would average from 30 to 40, have been made with the greatest precision, the azimuth deduced through them will be erroneous, by the same quantity that the angles themselves are.

The best method therefore of preventing any accumulation of error, or in other words, of correcting the angular observations so as to reduce them to the usual proof, is to fix on various other points on the circuits, and ascertain by fresh observations in the same manner as at Station A, the true azimuth of the lines measured from these points, such as at B, E, G, F, I and D.

By this means, the error in the angular work between A and B is confined within those limits, *i. e.* if the azimuth of the first line from A is carried through the angular observations between A and B, and the azimuth so deduced of the first line measured from B, is + or — the azimuth found by observation, it is evident that the difference between the two azimuths is the error of the angular work between A and B, and can be corrected accordingly.

* We recommend the following method of ensuring the steadiness of the Theodolite during observations.—With a radius of about 2 to 3 feet, according to the size of the instrument, describe a circle on the ground, (having the station peg as a centre) by means of a piece of string fastened round the peg, and at the other end a small piece of wood, or any thing that will make a mark on the ground. Lay off this radius, six times round the circumference, making a mark at each point, and at every other point drive in firmly a tent peg to within a couple of inches of the surface, and rather inclining inwards towards the centre, on these three tent pegs, rest the legs of the instrument, which thus becomes isolated in the ground on which the observer moves.

In the same manner, the difference between the deduced azimuth and that by observation at Station D is the error of the angular work between B and D, or between I and D; in the latter case, the azimuth being deduced from the direction of Station I, and in the former from Station B. The same is applicable to the correction of the angular observations between all the other stations, viz., between B and E, E and F, F and D, E and G, G and I; unless some system of the kind is adopted so as to have a constant check on the deduced azimuth, the proof by traverse of the different main circuits will be very unsatisfactory, indeed, they will eventually as the survey progresses, be beyond proof altogether. We will here give an instance to show how necessary it is to have such a check on the deduced azimuth.



Suppose the four main circuits, as shown in the above diagram, to have been surveyed according to their numbers, No. 1 first, and so on, and that Station A was the point on which the meridian of the survey was first laid down; to complete No. 5 circuit, it is only necessary to start from Station B and close on Station C, and to reverse the angles and distances of the adjoining circuits, 1, 2, 3 and 4, to suit No. 5 circuit. If the azimuth of the work has not been tested in

any of the circuits 1, 2 and 3, the azimuth of the line at Station B is entirely dependant on the correctness of the angular work run through these circuits. Again, if the azimuth of the work has not been tested in circuit No. 4, the azimuth of the line at Station C is dependant on the correctness of the angular work run through the circuit No. 4.

We will suppose an error of 20 minutes in excess to have gradually accumulated at Station B, by the error of the angular work between A and B, and at Station C, we will suppose the reverse, viz., a defect of 5 minutes; it must follow, if the angular observations between B and C are made even with the greatest precision, that the azimuth deduced from B towards C must differ 25 minutes with the azimuth at C, as deduced from A; for the meridian of the work at B varies 20 minutes east with the true meridian, and the meridian of the work at C varies 5 minutes west of the true meridian, 25 minutes will therefore be the error of the addition of the angles of No. 5 circuit, and which must be corrected in, to prove the angular work. As circuits Nos. 1, 2, 3 and 4 are completed, it becomes necessary to throw this error into the new portion or side of No. 5 circuit, or between B and C. Here is the commencement of error in the whole Survey, the azimuth of the work, on the northern part of these five circuits is, by the above correction, more or less, incorrect; this erroneous azimuth is carried on from circuit to circuit, until the whole work is thrown out by it beyond proof.

The proof columns of the traverses of circuit No. 5 are added up, and large discrepancies are apparent, the station lines are all remeasured over and over again to find out the error, but in vain, the chain measurements are all perfectly correct, the error lies, in that the traverses of all the station lines between A and B have been calculated on a meridian, gradually increasing in error to the eastward up to 20 minutes at Station B, and consequently throwing every station more and more to the eastward of where it should be, until Station B itself

is thrown perhaps 3 or 4 chains to the East of its proper site.

The same as regards Station C. Every station between A and C is thrown gradually more and more to the west of its proper situation, until C itself is perhaps 30 or 40 links to the West of where it ought to be.

The consequence of this is, that whereas by measurement C is west of B, say 230 chains, by calculation it is 235 chains, this error of 5 chains must therefore be corrected all round, vitiating all the work of circuits Nos. 1, 2, 3 and 4, or else it must be crammed in between B and C, on the only side of the new work, and thus increase the difficulty when the exterior circuit on No. 5 comes to be calculated.

We leave the Surveyor to act according to his inclinations in this dilemma, but at the same time strongly advise him to do neither, but to go back and re-observe his angular work, and satisfy himself of the cause of this accumulation of error, which will increase in every fresh circuit, if he does not do so. All this might have been obviated by a careful test of the azimuth at two or three intermediate points between A and B, and once at C itself, when the azimuths of all the lines between A and B would not have deviated more than a minute or two from the true meridian, and the error of the circuit (for some error there must be) would have been within the correction allowed.

The best points to select for the purpose are the triple-boundaries of Pergunnahs, which form the starting and closing points for other circuits, the azimuth at these points being tested, any circuit emanating therefrom will be sure of being started correctly.

This method of testing the azimuth at different points is an excellent check on the angular work of the Assistants, for as they are not made acquainted with the observed azimuth at these several points, the error of their work is at once detected, the difference between the deduced and observed azimuths

showing it. It is usual to take the magnetic azimuth of the back line when commencing a circuit, to ascertain the variation of the needle at starting, and to continue observing the magnetic azimuth of every 10th or 15th line on the circuit, with the view of checking any very gross error made in the angular work and on closing the circuit, the azimuth of the last line is also observed; but these magnetic azimuths cannot serve in any way in correcting the angles, for the needle is not to be depended on for the accuracy that is requisite in correcting the angular work of the circuits.

The usual method of correcting the angular work of main circuits is to divide the error all round the circuit, in the case of the *first* circuit, and in other adjoining circuits to divide the error, through the new work; but for an example, let us suppose No. 1 circuit, Page 329, to have consisted of 200 angles, and to have an error of 40 minutes, in excess of what the Theorem requires for proof; we will also suppose that between A and B, there were 60 angles observed, between B and D 70 angles, and between D and A also 70, making up the 200 angles of the circuit.

By this method of correction, 12' would be deducted between A and B, 14' between B and D and 14' between D and A, making up the error of 40' at the rate of 1' for every 5 angles. It is found, however, by testing the azimuth at B and D, that the correction to be applied between A and B, is — 20', between B and D — 25', and that consequently between D and A it must be a correction of + 5'.

By the former method of correction, the deduced azimuth at the point B will be diminished 12', at the point D 26', and by deducting 14' between D and A, the sum of the angles will prove.

By the latter method, the deduced azimuth at the point B must be decreased 20', at the point D 45', and between D and A, 5' must be *added* to prove the angular work.

The difference between the two methods of correction is, that the former is done by guess, and the latter by actual

Astronomical observation, and we think it is but too evident, which is the one most likely to give the best results.

In the preparation of main circuits, where a large river forms the boundary on one side, the stations should be taken along one side only, and when the adjoining main circuit is prepared on the opposite side of the river, its stations should run on the opposite side, leaving the river to form a circuit of itself; if this is not done, and the stations on one side of the river are made common to both circuits, it involves the necessity of crossing the river every time a village has to be closed on a main circuit station which is not always practicable.

Also, should the work of the season not extend beyond the river, it is only necessary to preserve the two extreme stations on the river to connect the work of the next season, and we therefore advise that a river should always be made the boundary of a main circuit, even should it not be the boundary of the Pergunnah; there is no more objection to dividing a Pergunnah into two circuits, than there is to enclosing two or three small Pergunnahs within one main circuit; and a river offers many facilities in this country, to laying down by intersection prominent points, such as mosques, temples, &c. which are often found on their banks, and perhaps not visible from the interior part of the Pergunnah.

If it becomes necessary to cross the river during the progress of the main circuit, the distance across should invariably be triangulated and the base of the triangle ought always to be *at least* one-third of the estimated distance. The Tindal who prepares the main circuit should always clear a line for a base, whenever it is necessary to cross a river, and not leave it to be done at the time of survey; this man must also take the leading flag during the survey of his circuit, for being acquainted with all the stations, much valuable time is saved, which would otherwise be lost, were the leading flag taken on by a classie who had to hunt out every station.

It is absolutely essential that these main circuits should be surveyed with the greatest care, and the computations carried on under the Superintending Officer's own eye. Instruments of not less than 7 inch diameter should be specially set aside for this purpose, and on no account ever entrusted to the Native Assistants. The carrying out of this system, in all its integrity, is most strongly insisted on by the Departmental Rules. The main circuits are intended to free the general results from the accumulation of error, which otherwise would necessarily be engendered by building up one small polygon on another; they should therefore never enclose a less area than 50 square miles, and they may average from that to 100 square miles.

It may be perfectly easy, instead of making a *bonâ fide* circuit of this description in the field, to extract the sides of all the exterior villages bordering on a Pergunnah, and *manufacture* a traverse of the required description, and so evade the real intent and meaning of the order, merely for the sake of the slight extra trouble caused in going round a main circuit. The inefficient supervision over Assistants will cause this, and as the consequences are most fatal to the value and character of a survey, too much care cannot be observed to guard against it, the proof of the work never can come out so satisfactory, and therefore it is liable to accumulate error beyond the means of reducing it within the allowed correction.

Each part of the work is rendered independent by these means: the larger circuits being measured with greater care and precision and with larger instruments than the smaller, the errors are not only detected and made apparent, but they can be confined within the space wherein they were generated, merely by dispersing the error of the subdivisions or village circuits, of which they are composed.

CHAPTER XIII.

ON THE METHOD OF PREPARING AND SURVEYING VIL- LAGE CIRCUITS, AND FILLING IN TOPOGRAPHICAL DETAILS.

SIMULTANEOUSLY with the preparation of the main circuits, line-cutters are detached for the village circuits, and they proceed to prepare their villages for survey as shown in Chapter XI. No definite rules can be laid down for their guidance as to where they should commence their work, as it depends very much on the size and shape of the Pergunnah or main circuit; as a general rule, they should be told off to main circuits in the proportion of one party to every fifty villages contained within the circuit, thirty villages being considered a fair month's work for one line-cutting party.

Some Surveyors prepare their villages for survey by commencing from the main circuit Stations and working inwards towards the centre of the Pergunnah; others, the reverse, commencing from the centre, and working on to the main circuit, and there closing their work: the latter is, however, preferable; the former is dependant on the main circuit Stations being previously prepared, which cannot always be the case, whereas in the latter, the village line-cutter only requires the main circuit stations to close the several villages situated on the boundary of the Pergunnah.

A little practice in the field will soon show a Surveyor the best method of telling off his line-cutters, the only care required, being that of *taking up* or *closing on* one another's Station

points in adjoining villages, and of limiting their offsets within the prescribed maximum of 5 Chains on each side of the chain line.

A sufficient number of circuits being thus marked out, and all the stations duly prepared ahead of the surveying party, the mode of proceeding will be best explained by an example—

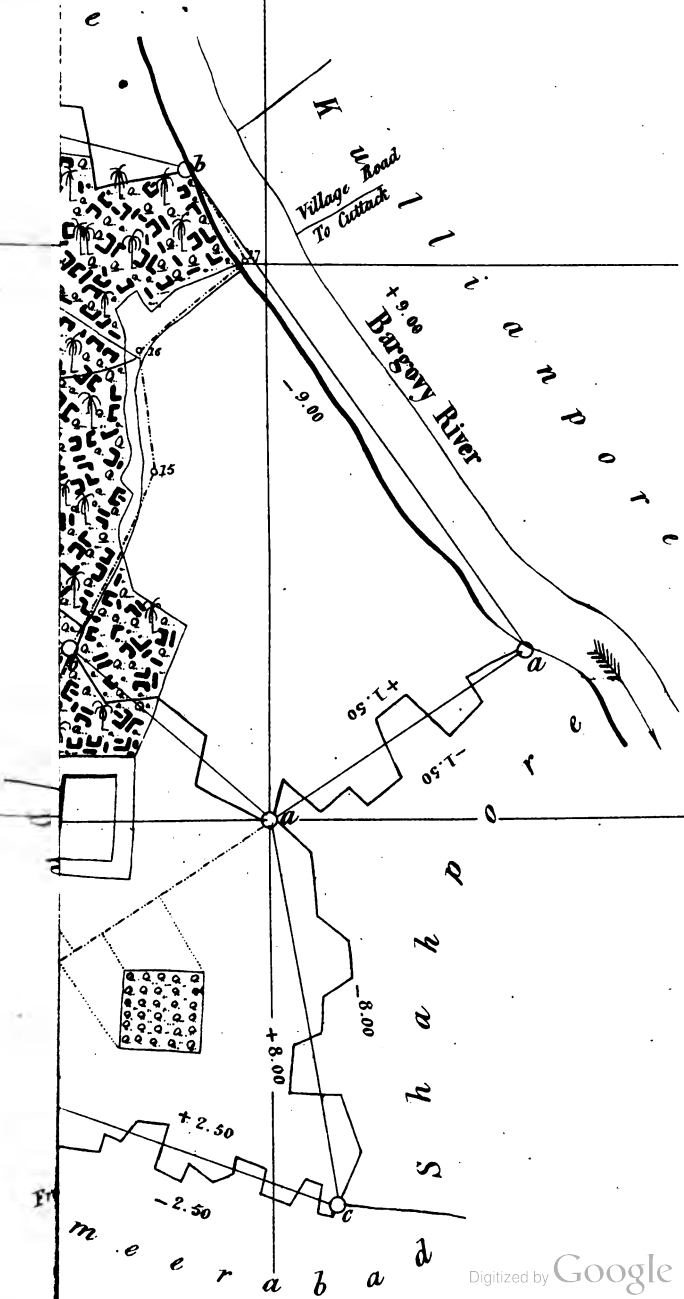
In the adjoining Plate VI., let the Station lines GF, JA, AB, and BC, be four lines previously surveyed on a main circuit, and the three enclosures marked 1, 2 and 3, be the irregular figures formed by the boundaries of the villages contained within them.

For the survey of village No. 1, or Mahmoodpore, start from Station C of the main circuit, observe the interior angle BCa , thence proceed to Stations a, b, c, d, e , observing the interior angles of the polygon $Cab, abc, bcd, \&c.$, measuring the lines $Ca, ab, bc, cd, \&c.$, and closing on Station J of the main circuit, observing the interior angle eJA ; to complete the angles of this polygon, to obtain the necessary proof, the angles JAB and ABC of the main circuit must be added to the angles above taken.

To survey the village of Patpore, No. 2, commence from Station c of No. 1, Mahmoodpore, observe the interior angle dca , and proceed round measuring the several lines and keeping the village itself to the left-hand, observing the interior angles $cab, abc, \&c.$, and closing on Station G of the main circuit, observing the angle cGJ ; to complete the interior angles of this polygon, the angle GJe is required, obtainable by deducting the angle eJA of No. 1, Mahmoodpore, from the main circuit angle GJA , and also the angles Jed and edc , obtainable by reversing the angles deJ and cde in the adjoining village, No. 1.

For the survey of No. 3, or Jehanabad, commence at Station a , of No. 1, Mahmoodpore, observe the interior angle baa and proceeding round through the Stations a, b, c, d , as before, close

Specime



the survey of the village on Station *a* of No. 2, Patpore, observing the interior angle *dac* ; to complete the interior angles of this polygon, the angles *acb* and *cba* are required, the former is obtained by taking the sum of the two angles, *dca* of No. 2, Patpore, and *bcd* of No. 1, Mahmoodpore, and deducting it from 360° , leaving the angle *acb* for No. 3, Jehanabad, and the latter, by deducting the angle *abc* of No. 1, Mahmoodpore, from 360° , leaving the angle *cba* of No. 3, Jehanabad.

In this manner are the angles obtained from adjoining villages, to complete the angles of the village under survey, so as to meet the required proof, and it is of actual necessity, that when once angles are corrected for a village the outward angles, or the sum of any two at a triple-boundary Station deducted from 360° , must be taken to the minute for the adjoining village, otherwise the azimuths of the several lines in the adjoining villages would differ, which for the general proof and accuracy of the work, it is incumbent that they should not.

The Station lines are measured at the same time that the angles are observed, and they are also common to the village under survey, as well as to the adjoining village. For instance, the station line *Ca*, in Mahmoodpore, is common to the village adjoining it, Shahpore, as also the offsets on the line, defining the boundary of Mahmoodpore, and consequently also that of Shahpore. The offset calculations are equally transferable by reversing the sign; if the balance area is *plus* for Mahmoodpore it is *minus* for Shahpore, or *vice versâ* ; the azimuth of the line *Ca* by being reversed becomes the azimuth of the line *aC* in Shahpore; the latitude and departure of the same line in Mahmoodpore is likewise applicable to Shahpore, for the distances on the meridian and Perpendicular being Northing and Easting for the former village, become Southing and Westing for the latter, so that in every village surveyed, the angles, bearings, distances, and traverse calculations, are all

so much work done for the village itself, as well as piece meal for the adjoining villages also.

The Boundary common to two villages should never be twice surveyed, not only on account of the extra work it entails, but to prevent discrepancies either in the angular and linear measurements, or in the offsets to the Boundary which would probably arise, and cause much confusion in the work.

In putting up work, it is always customary to enter *first* in the Traverse Table, the angles, &c., of the old work of adjoining villages, commencing at the Station where the new work closed, and following them round, until arrived at the Station where the new work commenced, and then to enter the angles, &c., of the new work. Thus, in putting up in a Traverse Table the three villages shown in the plate, the Stations would be entered as follows, for all villages adjoining them.

FOR MAHMOODPORE.		FOR PATPORE.		FOR JEHANABAD.	
Names of Adjoining Villages.	Stations.	Names of Adjoining Villages.	Stations.	Names of Adjoining Villages.	Stations.
Joynuggur.	J	Joynuggur.	G	Patpore.	a
	A		J		c
	B	Mahmoodypore.	e	Mahmoodypore.	b
Ameerabad.			d		a
	C	Jehanabad.	c	Shahpore.	
Shahpore.			a		a
	a	Chandpore.	b	Kullianpore.	
Jehanabad.	b		c		b
	c	Dhakooryah.		Manpore.	
	d		G		c
	e			Janpore.	
Patpore.	J				d
				Chandpore.	
					a

The peculiar method of keeping the Field-book of the angular observations and Chain measurements, is of great assistance, in ascertaining the starting and closing Stations of villages.

The Field-book of the three villages in Plate VI., is shown on the next page; the left-hand column of the Field-book containing the angular observations, and the right-hand column, the Chain distances. Letters have been made use of to denote the Station points for the sake of explanation, but in the Field this is unnecessary; the letters are generally added when the Traverse of the village is put up, the Native Surveyor in the Field being guided solely by the names of adjoining villages for starting and closing points.

For instance, in the survey of Mahmoodpore, he notes down, having commenced the survey at $\angle 165^{\circ} 40'$ of main circuit, triple-boundary of Mahmoodpore, Shahpore, and Ameerabad, the two main circuit distances being 33.01 Chains and 24.68 Chains, measured to and from this Station during the progress of the main circuit. Mahmoodpore being the village under survey, its name is entered at the bottom of the page and also on the left-hand side of the Field-book, the adjoining village being Shahpore, is entered on the right-hand side and continued until he arrives at the first triple-boundary where the exterior village must of course change. Here a line is drawn across to the right, thus denoting the Station a triple-boundary one; Jehanabad is then entered as the adjoining village, until arrived at the next triple-boundary, and drawing a line again across his Field-book, he enters the name of the next adjoining Village Patpore, continuing this on until he closes on the main circuit, where he notes, closed on $\angle 191^{\circ} 40'$ of main circuit, distances 33.40 Chains and 28.60 Chains, being the triple-boundary of Mahmoodpore, Patpore and Joynuggur.

Closed on \angle 99° 30' of Patpore. Distance 68.32 and 38.22.		Closed on \angle 138° 30' Main Circuit. Distance 34.50 and 31.01.	
9.30	Patpore.	55.30	Joynggur.
246.20	28.03	277.00	58.20
123.10		138.30	
a		G	
232.00	Chandpore.	208.30	Dhakooryah.
154.40	62.70	139.00	22.60
77.20		69.30	
d		c	
93.01	Janpore.	30.30	
302.00	59.84	144.20	
151.00		252.10	
c		b	
57.01	Manpore.	298.30	Chandpore.
278.00	61.80	199.00	
189.00		99.30'	
b		a	
267.00	Kullianpore.	169.30	Jehanabad.
178.00	32.20	118.00	
89.00		56.30	
a		c	
312.00	Shahpore.	Commenced \angle 93° 30' of Mahmoodpore. Distance 29.00 and 22.50.	
208.00			
104.00			
a			

Jehanabad.

Survey of Village Patpore.

Survey of Village Jehanabad.

Commenced \angle 140° 50' of Mahmoodpore. Distance 40.61 and 26.50.

is the first village to his right-hand, and he continues on, noting the names of adjoining villages and triple-boundaries, until he closes on the main circuit at $\angle 138^{\circ} 30'$. In the same manner Jehanabad is surveyed, commencing at $\angle 140^{\circ} 50'$ of Mahmoodpore, and closing on $\angle 99^{\circ} 30'$ of Patpore, and so on, for the survey of the adjoining villages, until all contained within the main circuit are taken up.

The main circuit Field-book is kept in the same manner as the village circuit, with the exception of the names of villages within and without the circuit, being entered on each side of the columns.

We have before said, that in *all* survey operations, work should always be carried on from *whole* to *part*, and never from *part* to *whole*; this is a maxim which should always be borne in mind, and in the putting up of work, carried on under the Traverse system, it requires especial attention; many Surveyors are in the habit of setting up the Traverse of every village as it is sent in by the Native Surveyor, proving and completing it at once.

This method, unless the angular work is done with the greatest care, is attended with some risk, for though to all appearance the villages may be correct, when the work is closed on the opposite side of the main circuit, the azimuth of the village Station lines is sometimes found to differ several minutes with the azimuth of the main circuit Station lines, even at times to $\frac{1}{4}$ and $\frac{1}{2}$ a degree; this is owing to the angular work of the villages having been erroneously corrected. The best mode of setting up villages, so as to ensure as much accuracy as possible, is to put up the angular work of the villages as they are sent in, but to make no corrections nor enter the azimuth of any of the Station lines, until some 20 or 30 villages are surveyed; then take the *exterior* angles and Station lines of the exterior villages contained within the lot, and deduce the azimuths of these several lines from a corrected azimuth of former

work, verifying it by a junction on the main circuit or other proved work; this done, set up the Traverse of the exterior of these 20 or 30 villages and prove it in the usual way, when the errors of the interior villages or circuits can all be kept within this circuit. It is advisable, if the above is not attended to, to subdivide all main circuits, into three or four smaller circuits, which can very easily be done, by taking up the Station lines prepared for the village circuits, and proving the Traverse of each of these smaller circuits, which will tend much to the general correctness of the work within the main circuit.

The whole of the Village Circuits being thus represented, and their peripheries defined by accurate angular work, it remains to fill in all the topographical details within these small polygons, the Stations of which form so many convenient bases, on which this part of the operations may be laid down with very great facility and precision. For this duty the instruments employed are, the Circumferentor, the Prismatic, and the common Surveying Compass, together with the Drawing Board and T Square, and it has been found that the common Compass or Circumferentor, is preferable to the Prismatic Compass, which latter from such constant exposure is liable to get out of order, the card warps with the Sun and atmospheric changes, and in the hands of Natives it is not so easy to use, or to fix in a horizontal position. For topographical work generally, and filling in triangles of any extent the Plane Table (page 115) is in general use, and is the best contrivance for the purpose, but for details confined within such narrow limits as Village Circuits it is not necessary, and the practice therefore on the Revenue Surveys is to employ a simple Drawing Board and T Square, (page 226) which is far more portable, can be carried in the hand, and with the aid of the common rectangular or circular Protractor enables the Assistant to draw the whole of the topography in the Field with great despatch, and is peculiarly suited for Native Agency.

Prior to commencing this interior detail survey, the Native Assistant is furnished with the board containing all the Station lines of a certain number of congregated villages drawn on the paper, and which is mounted in the frame of the board; from 8 to 10 polygons, or as many as will conveniently come on the paper, are thus given out, leaving a small space on either side of the paper for recording the several bearings and distances, which may be required for replotting the work afterwards and to detect errors, the Station lines together with the meridian line drawn completely across the paper being inked in; the T Ruler working against the lower edge of the board by means of its projecting head, forms parallels to the given meridian at any given point. This line, however, represents the *true* meridian on which all the angular work is based, and as the interior details are filled in with the *magnetic* needle, it is imperative before a single observation can be reduced to paper, that the *variation of the needle* be clearly ascertained, and this is invariably done by any of the methods mentioned in Part V., and recorded on the instrument itself, or on the lid of the box, or other convenient place. If the variation be Easterly (as it now is in this country) the bearing actually observed must be *increased by the quantity*, before it can be protracted on the board, and if Westerly, the variation must be *deducted*. Every needle in use with a survey will be found to differ with reference to its polarization; all work therefore produced by means of this treacherous instrument, must be very carefully carried on, due allowance being made so as to reduce every needle to the same meridian.

To obviate, however, the necessity of constantly adding this quantity to the bearings taken in the field, the meridian line may so be fixed on the board as to preclude any addition or subtraction whatever. Before the Stations of the polygons are pricked off on to the board from the original rough office protractations, it is well to let the meridian line drawn on the

If true Meridian = 90°
the magnetic bearing will be
346

87.30.
2.30

board by the T Rule, stand for the *magnetic* meridian, and then to lay off the variation of the compass to the left-hand or *Westward* of this line (the variation being Easterly) thus giving the direction of the *true* meridian, and on this to adapt the several points of the Circuit Survey by fixing the *true* meridian line of the original map, with the true one on the Board. The whole of the Station lines are thus transferred from the *true* to the *magnetic* meridian (with reference to the parallels drawn with the T Rule) and it is only necessary to protract the bearing actually read on the compass, without any alteration whatever.

For the more ready adaptation of the magnetic to the true azimuth, on which the lines of any village in particular may have been calculated, it is only necessary for the topographical detail Surveyor to take the bearing very carefully of any of the Boundary Station lines from which he may commence his work, and the difference between this observed bearing and the computed one, with which he has been furnished on his board, is the variation of the needle of the instrument with which he is about to lay down the details. This method is a very good one, as the needles of prismatic and the common surveying compasses are so constantly getting out of order, that the variation cannot be observed too often, and by taking this precaution the work will be found to plot infinitely better, and little difficulty will be met with in closing on the Stations on the extreme side of the board. To enable the interior detail survey to proceed in this manner, it will be observed that the boundary operations must be so far in advance as to permit of the Village Station lines being plotted on the large office sheets (or *Chuddurs**) for transfer to the

* The *Chuddur* Map consists of a sheet of Imperial Paper with squares of 80 Chains correctly drawn on it, the lines representing meridians and perpendiculars, and on which all the Village Circuits are protracted, and severally joined on or built up, one on the other, in succession as they are surveyed, and by which much labor is saved, the squares giving also a good estimate of the area thus inserted, for reporting progress monthly.

board, but this may sometimes not be practicable (although if the survey is properly and systematically conducted this part of the work will always be brought up) in which case the board can still be used precisely in the same way, the Native Surveyor recording all the Stations he meets with, which can be identified afterwards with the original skeleton plan, and inserted thereon without any difficulty, in which case the survey may be plotted on the magnetic meridian, and afterwards when the details are transferred to the *Chuddur*, the proper allowance must be made for the variation of the compass.

The detail Surveyor proceeds to lay down all the topographical items to be met with, in the following manner:

In the Village No. 1, Mahmoodpore, (Plate VI.) he commences by drawing a meridian line with the T Rule through the $\odot a$, takes the Bearing of the $\odot 1$ and measures the offsets on each side, wherever any object presents itself, as shewn by the dotted lines, thence observing the Bearing of $\odot 2$, proceeds in a similar manner, noticing where the corner of the village land touches the line and sketching in the tops of trees there situated; this last Bearing is protracted from another meridian line drawn through $\odot 1$. From $\odot 2$ he proceeds to $\odot 3$, and closes on $\odot c$ to check the correctness of his work, this should never be omitted wherever practicable; starting again from $\odot 2$, he observes the Bearing of $\odot 4$ proceeding along the road, and taking up the measurements of the tank on the right-hand side. From $\odot 4$, he closes again on $\odot e$, and returning to $\odot 4$ measures round the village land to $\odot 5$ and 6 , meeting the $\odot 2$; proceeding thence along the road through the village site to $\odot 7$ he closes on the Boundary Station *b*, taking up any object of note within reach.

In the same manner the details of the two Villages Patpore and Jehanabad are filled in, following the dotted lines as shewn in the Plate; not only are the conspicuous objects and all

geographical items thus laid down, but all the different descriptions of land separated, viz., cultivation, waste, fallow, sites of villages, and land fit for cultivation, the area of which being required for settlement purposes, is found by triangulation on the map.

In the survey of the Village Boundary Circuit of course a great portion of the details are taken up, every thing that comes within reach of an offset on either side the Station lines, as well as by intersection from convenient points of the polygon, is duly recorded in the Boundary Field-book and shewn on the plot of the Village Circuit, and these items form good checks against any errors made by the interior Surveyor when his work is compared with, and transferred to the Circuit map.

With such an extent of Native Agency as is employed on all the Surveys in India, it is a great object to plot all work in the Field, it saves an immensity of labor, and the chances of accuracy are greatly increased; by the aid of the Drawing Board much can be sketched in, and the first impression of a locality is not lost, but at once represented on the plan. Field-books kept by Natives, ignorant of English, may better be imagined than described, it is always difficult for any Surveyor to understand fully a Field-book kept by another person, but where novices on 10 or 15 Rupees per mensem attempt to keep such records, and hurry on at the railroad pace of a Revenue Survey in the present age, we do not envy the person who has to protract from them. The Native Surveyor who brings in his Board well filled, displays at once what amount of work he has done, and a Superintending Officer is able to see at a glance, what confidence is to be placed on the topography so defined.

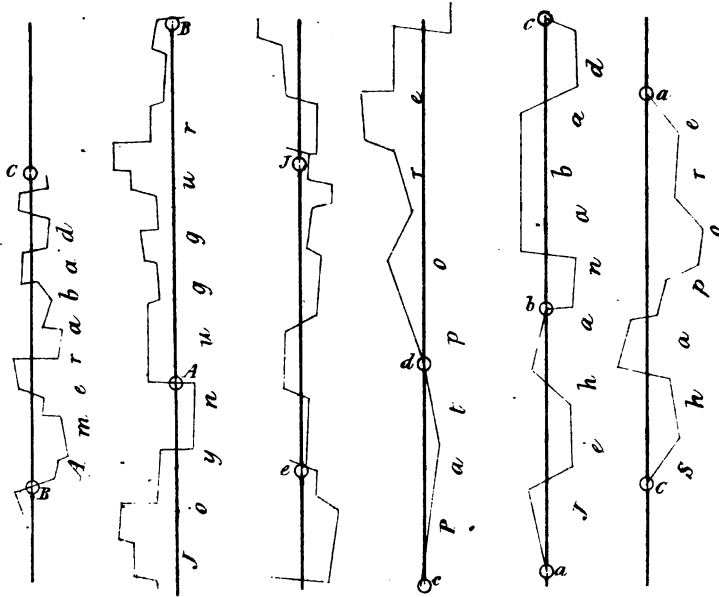
The most intricate and laborious part of the work, is the Survey of the Village Boundaries; these are so tortuous and irregular, in Bengal especially, that to lay them down, the greatest care is required, and as this is the chief object of the operations, it is usual and highly desirable that the

boundaries should likewise be accurately plotted in the Field. Indeed it frequently happens that these offsets are so difficult, owing to the extraordinary bends and turns in the Village Boundary, and there being no visible landmarks or hedges and ditches to divide property, as in other countries, that to insert them in a Field-book only, would render the map liable to inaccuracy, whereas by plotting them on the spot, the eye at once sees whether the turns and bends on the paper correspond with the marks as erected on the ground, and a comparison can, at the same time, be instituted with the rough sketch furnished by the Settlement Officer, and any discrepancy enquired into and corrected on the moment.

On this account the boundary offsets demand much time and careful attention, a separate Native Surveyor is therefore appointed for the duty. The angular and linear measurements of the Station lines of the polygon furnish the data for the traverse computations and are therefore urgently called for, and the Sub-Assistant is able to proceed ahead with merely this skeleton work: the Village Boundary then can be taken up by a distinct Assistant, proceeding a little in the rear of the Theodolite party, or it may be left for the interior detail Assistant, who has ample opportunity and leisure to perfect this portion of the work; the whole of the Station lines of the polygons being given out to him on the drawing board, he has only to re-measure the Station lines round the village and plot all the offsets as he advances.

This re-measurement of the Station lines may appear to increase the business, but the advantage gained by careful and correct boundaries being taken up, more than counterbalances the extra duty. This is the practice on some surveys, whilst on others the angular observations and boundary offsets proceed simultaneously, the division of labor being generally regulated according to the peculiar fancy of a Surveyor, and with reference to the means at his disposal.

In the latter case, however, it is necessary to provide means for the protraction of the offsets on the Board in the Field, where of course the circuit lines of the polygon are not pro-



curable, not having yet been surveyed. For this purpose simple straight lines are drawn across the Board at a distance of about 20 Chains from each other. On these lines each Station line of the Polygon is marked off, and the offsets plotted on each side. Thus, in the above diagram, *Ca* represents the first Station line of the Village of Mahmoodpore Plate VI, *ab* the next and so on to *BC*, the offsets are all laid down on either side by scale, and when the papers are taken off the Board, each separate Station is applied to the same point on the circuit map, after it has been properly protracted, by turning and shifting the paper as required, and the offsets either pricked or traced off; each line is thus identified with its own proper azimuth, and the distances being the same, and each following in due succession,

there is no difficulty whatever in transferring these offsets as drawn in the Field, to their legitimate place on the circuit map.

This system is very frequently practised, as it enables the Assistant to get a great deal into a small space, and it is particularly easy for Natives, and is dependant on no other work being ready before hand. As an office document, also, it is plain and intelligible for others to make use of.

The boundary operations proceeding angularly, the Bearings of each line are not attainable at the moment without some loss of time, but the relative angular measurements of each line with the other, can be protracted on the Board from the angular observations if necessary. To do this, however, it requires some management and foresight to keep the plot within the limits of the Board, and Native Assistants are apt to confuse this. The method above described, therefore seems the most preferable for perspicuity and despatch.

The general introduction of the geographical features of a country, must be provided for by the many ways of common surveying already described in different parts of this work, and the same system or principles, must be adhered to, as laid down in all the English works on the same subject. Practice alone can fully develop to the Surveyor all the niceties and peculiar facilities for gaining the greatest amount of topographical information, with the least amount of labor, and by a reference to the several Plates and Diagrams herein given on the subject, it is hoped, that with the easy explanations we have endeavoured to append to them, the reader, (and the *beginner*, for whose especial use this work has been prepared,) will find no difficulty in applying the theory to practice, when he is placed in the Field and left to his own resources.

In sketching hilly ground, great care and superior judgment are necessary. Small ranges of hills, when met with, generally form the boundary of some pergunnah or other local subdivision, and therefore come under the immediate cognizance of the

Surveyor or his European Assistants, and are properly intersected and laid down by triangulation, in connection with the angular work of the main circuit. This duty should, on no account, be entrusted to any Native Assistants who are only qualified to follow a simple routine course, which has been duly prepared and marked out for them, and who perform mechanical duties very well, without understanding the reasons. Unless the Surveyor himself is careful to superintend, personally, this the most difficult part of his operations, the faithfulness and style of his general maps will be inevitably damaged. The operation of sketching the features of ground, cannot be rendered intelligible by description alone, nothing but a matured judgment and experience on the part of a Surveyor, will enable him to attain to any degree of accuracy in this respect. We defer all remarks on the shading and delineation of hills for another chapter.

CHAPTER XIV.

ON ROUTE SURVEYING AND MILITARY RECONNOISSANCE.

ROUTE Surveys, although they do not come under the head of scientific or accurate works, can, however, be made to approximate so near the truth, as to become very useful in filling in the topography of countries that have not come under more detailed operations.

Military Reconnoissance may be said to form a part of Route Surveying, for the latter, in a military point of view, would be of little use without the former, and a sketch of the country combined with an explanatory statistical report, constitutes what is called a Military Reconnoissance, and in which the importance of the *sketch*, or the *report* predominates according to circumstances.

This duty is generally performed in India by the Quarter Master General's Department, but opportunities are numerously afforded to many other Officers in this country of obtaining information of various kinds, which might be eventually useful to the Government, in one way or other.

“ The object for which any reconnoissance is undertaken, naturally suggests the points to which the attention of the Officer should be principally directed; if, for example, it is merely to determine the best line of march for troops through a friendly or undisputed country, the state of the communications, the facilities of transport, and possibility of provisioning a stated number of men upon the route, are the first objects for his consideration. If the ground in question is to be

occupied either permanently, or for temporary purposes, or if it is likely to become the seat of war, his attention must be directed to its military features; and a sketch of the ground, with explanatory references, together with a full and correct report of all the intelligence he can collect from observation, or from such of the inhabitants as are most likely to be well acquainted with the localities, and most worthy of credence, will demand the exertion of all his energies; upon the correct information furnished by this reconnoissance, may depend, in a great measure, the fate of the army."*

Despatch and simplicity of execution are the great things to be aimed at in a military sketch, and although the greatest possible accuracy may not be absolutely necessary, yet every precaution should be taken as far as circumstances will admit. Its objects being so different from the more operose surveying, the shortest, easiest and most certain methods of practice will ever be entitled to the greatest attention.

The principles of military sketching cannot differ essentially from those of Surveying; they both consist in determining the sides and angles of real or imaginary figures upon the surface of the earth: these can always be resolved into triangles, by means of which we lay down these figures upon paper to any required scale. But the *practice* differs very considerably, and it is for this reason that they are called sketches rather than surveys, because so much of them is usually done by the eye, instead of being a continued series of angles and measured lines, as in the more elaborate surveys. Many instruments have been contrived for military sketching, each of which has some advantage peculiar to itself, but the prismatic compass and pocket sextant, as described in pages 110 and 136, appear to be the best adapted for the kind of work. To these must be added a case of leather to hold the sketches, and an ivory protractor together with a pencil, and which are

* Frome on Surveying.

generally contained in the sketching case, to lay down the angles and the distances.

One of the most essential things to be acquired, is that of judging distances with accuracy; upon this every thing depends in a hasty sketch, where instruments are sparingly used or excluded altogether, a few days' practice will enable an Officer to estimate with tolerable accuracy, the length and average quickness of his ordinary pace, as also that of his horse, as on a rapid reconnoissance he must necessarily be mounted, and the habit of guessing distances, which can afterwards be verified, will tend to correct his eye.

An easy mode of judging distances is by marking on a scale or pencil, held at some fixed distance from the eye, the apparent diameter, or height, at different measured distances of any objects, the dimensions of which may be considered nearly constant, such as the average height of a man, a house of one or two stories, &c., will furnish suitable standards.

“The degree of accuracy of which a military sketch is susceptible, depends upon the time that can be allowed, and the means that may be at hand. If a good map of the country can be procured, the positions of several conspicuous points can be taken from it and laid down on the required scale; or a rough base may be measured, carefully paced, or obtained from some known distance, and angles taken with a pocket sextant or other instrument from its extremities, to form a tolerably accurate species of triangulation, which may be laid down without calculation, and within this the detail can be sketched more rapidly, and with far more certainty than without such assistance. No directions that can possibly be given will render an Officer expert at this most necessary branch of his profession, as practice alone can give him an eye capable of generalizing the minute features of the ground, and catching their true military character, or the power of delineating them with ease, rapidity and correctness.”*

* Frome on Surveying.

The adjoining Plate represents the form of a Report extracted from "Major Jackson's Course of Military Surveying"; and which should accompany all Route Surveys. This form was drawn up by Major Hector Straith, late Professor of Fortification, at the Honorable Company's Military Seminary at Addiscombe. It is the result of his own observations when serving in India, and is well suited to the purpose.

The limits of this work will not admit of our pursuing this interesting subject any further, but the following memoranda, extracted from the same work, which are nearly a transcript of those issued by Sir George Murray for the guidance of the Officers of the Quarter Master General's Department, during the Peninsular War, will serve to point out the principal objects to which an Officer employed in the important duty of reconnoitring, should direct his attention.

He must seek to acquire a good general knowledge of the country upon which he is to report, regarding its natural and political divisions, and principal features. He will then go into detail, dividing the subject into different heads, as:—

I. *The peculiar nature of each district of country, and its productions.*

Particularizing what parts of it are mountainous or hilly, and what are level: whether the hills are steep, broken by rocky ground, rise by gradual and easy slopes; or, if the ground is undulated only in gentle swells. Whether the connexion of the high lands is obvious and continued, or if the heights appear detached from each other. In what directions the ridges run, and which are their steepest sides. The nature and extent of their vallies, and ravines—where they originate, in what directions they run, whether difficult of access, or to be easily passed.

Whether the country is barren or cultivated, and what is the kind of cultivation—whether vines, or olives, or corn; and if the latter, what kinds of corn are grown, and in what parts it is most abundant. If a country of pasturage, whether it is

grazed by cattle, by sheep, or by horses, and in what numbers—what parts of the country are open, and what are enclosed, and the description of the enclosures—whether small or extensive, formed by stone walls, ditches, hedges, or fences of any other kind. What parts of the country are wooded, and whether with grown timber, or coppice wood; and with what species of trees—what the nature of the soil.

What is the nature of the country, in reference to the operations of troops—what parts of it are favourable for the acting of cavalry, and what for infantry only.

II. *The rivers and minor streams, and canals.*

The sources of rivers, and the direction of their course—whether they are rapid or otherwise; their breadth and depth, and what variations they are subject to, at different seasons of the year—the nature of their channels and of their banks—whether rocky, gravelly, sandy, or muddy—of easy or of difficult access: the bridges across them—whether of stone or of wood; their breadth and length; if accessible to artillery, and capable of bearing its weight. The nature of the fords, if always passable, or at certain times and seasons only—whether their situations change.* What rivers are navigable, and from and to what points, and by what description of vessels or boats. The ferries—their breadth, and the nature of the landing place on each side; what description of boats are used at them—how many men, horses, or carriages, each boat is capable of conveying—how much time the passage requires, and in what manner it is performed. Canals—their course, breadth and depth; the nature of the traffic carried on upon them—the number of boats usually to be found at different places, and the nature and dimensions of the boats; also, whether they are tracked by men or horses, or how otherwise navigated. Lakes and inlets of the sea—their situation, extent, and boundaries;

* A ford should not exceed in depth 3 feet for infantry, 4 feet for cavalry, and 2½ feet for artillery.

what description of vessels can navigate them, &c., together with such of the above observations as are applicable to them. Marshes—their situation and extent—whether passable for troops in any part; and if they continue throughout the year, or exist only during the wet season.

III. *Population, resources, accommodation for troops, &c.*

The size of towns and villages, and the number of their inhabitants; and whether well supplied with provisions, or not. The number of houses, as also of churches, convents, or other public buildings—whether the houses are large and commodious, or small and mean—what number of troops could be accommodated in private houses, and what in public buildings, what stabling there is, or other cover for horses—if the town is walled or open, favourably situated for defence, or otherwise—if capable of being strengthened, and by what means. Similar observations in regard to detached convents, gentlemen's seats, farms, and other separate buildings. Plans or sketches of walled towns, defensible villages, or detached buildings, should always accompany the reports upon them. The number of carriages, horses, mules, or draught oxen, in possession of each town, village, or farm, should be stated; and what is the general means of conveyance made use of in the country—what mills exist in the town or vicinity, and whether turned by wind or water;—the bake houses, and quantity of bread they can produce in a given time; whether the place is unhealthy, or not; if it be, whether it is in general unhealthy, or only so at particular seasons.

IV. *Roads.*

Particular information must be obtained respecting the roads, in the description of which it is impossible to be too minute; the general nature of each road, as also all the variations which occur in it, from distance to distance, should be accurately described—whether the road has been regularly made, or appears to have been formed only by the use of the people of the country; whether it is fit for artillery, or practicable for

any description of wheel-carriage; for cavalry, or for infantry only—over what description of soil it passes; whether rocky, or gravelly; sandy, clayey, or earthy; and to what injuries it is liable in bad weather; whether it is easily repairable or not, what materials are requisite for that purpose, and whether they are to be found in the neighbourhood; whether any bad parts of the road, or the narrow and embarrassed streets of any of the towns or villages, can be avoided, by going out of the road for a short distance; as, also, whether any great improvement could be made in the general direction of any part of the road, by adopting a new line altogether, for a considerable distance; and what work is necessary in either of these cases. Particular attention should be paid to the ascents and descents upon the road; whether they are gradual and easy, or abrupt, rugged, or stony, having short turns or other difficulties; whether the road is wide enough in those parts which go along the side of a hill, and whether it is even, or is canted off the level, so as to be unsafe for carriages. In those parts where the road passes between walls, or where it forms a hollow way between banks of earth, rocks, or other obstacles, its breadth ought to be measured, and it should be remarked also whether it can be widened, or the obstacles removed which confine it. The ferries, bridges, fords, &c., met with upon the road, should be particularly described; the possibility of obstructing or breaking up the road, so as to prevent its being used by the enemy; or of destroying the bridges or fords upon it, should be stated. The means of effecting these objects should be pointed out; as also the labour and time requisite for such a work. The distances of the places along the road should be given, both in the measures of the country, and in English miles, averaged as accurately as possible. The time required to travel the different distances, (at the ordinary walk of a man, or of a horse) should also be stated. The places to the right and left, near the road should be mentioned; their distances from the road, and at what points the communications to them strike off.

Whether there are any railroads, and what facilities they offer for the rapid transport of troops, artillery, provisions, &c.

Care must be taken that the names of towns, villages, rivers, &c., are spelt in the same manner as by the natives of the country, and when the spelling and the pronunciation differ very much, the name should also be written (in a parenthesis) as it is pronounced.

V. *Camps and Positions.*

All strong passes, posts, or more extensive positions, which present themselves either upon the line of a road, or in any other situation; as also all places favourable for encamping or bivouacing troops, either with a view to position, or with reference merely to convenience upon a march, should be particularly described—their situation, extent, facility of access, nature of soil, supply of water at all seasons, quantity and kind of wood, and whether in sufficient abundance for hutting the troops, or only for furnishing fuel. A sketch of the ground upon a pretty large scale, should always accompany these reports.*

In all reports, officers should state distinctly what parts of the information they contain rest upon their own personal examination of the objects in question, and what upon the authority of others; and, in the latter case, they should mention the source of their information, in order that a judgment may be formed of the degree of credit to which it is entitled.

Sketches of the above character may be, and frequently are rendered extremely useful, when time and opportunity permit nothing better, but in India where such vast tracts of country are almost totally unexplored, the Officers of the Engineer and Quarter Master General's Department, are constantly employed in time of peace in performing Route Surveys which partake of a higher order, and are carried on

* Sketches of positions should never be made upon a smaller scale than four inches to an English mile. More general sketches may be made upon a scale of two inches to a mile, and tracings of roads upon a scale of one inch to a mile.

with good instruments, and in the absence of all trigonometrical closing points, are checked by astronomical observations made with a reflecting circle or sextant, and an artificial horizon.

These surveys form our first geographical knowledge of all new countries, which are either annexed to, or under the protection of British rule. It therefore is of the greatest importance that they be conducted with some sort of system, that the materials may be compiled and put together in such a way, as to be useful in a general map. It will not do to commence from the peg of your tent or other indefinite object; every route should start from a fixed, and well known permanent point of departure, and close on similar objects, such as temples, mosques, puckha buildings or churches. This point of departure should be fixed either trigonometrically or astronomically, and if no such points are available at the time, they ought to be fixed as soon after as possible. If bits here and there are surveyed indiscriminately, without points of departure and closure, and without connection with themselves or with other people's work, gaps here and overlapping there, nothing but confusion can ensue. If in a campaign or line of march, the Surveyors start in the dark, and do not survey until the day dawns, all the ground traversed in the *interim* becomes an hiatus; *then* a route may be measured with vast accuracy, angles repeated and the greatest refinement observed, until the sun gets hot, when the survey stops in the middle of the road, and the Surveyor gallops home.

In this way many maps, of recently explored tracts, have been constructed, partly by guess and partly by measurement; to practical Surveyors, this may appear absurd, but such things, nevertheless, have been done.

The staple commodity for route, or Road Surveyors, is the perambulator. A few words, therefore, regarding this most useful and necessary instrument, will not be out of place. In the first place, all English perambulators should be condemned *in toto*, they are flimsy, bad in principle, and

incapable of working, except on a smooth road or bowling green, across country they go to pieces in a mile or two. There is nothing like the Madras pattern principle of the endless screw and differential plates. The large Madras perambulator, (page 107,) however, has two faults, the wheel is not sufficiently strong, and it is graduated to furlongs and yards, which is unscientific. Colonel Waugh's 10 mile perambulator, (page 109,) with decimal scale, is a very handy and accurate implement, and will stand any hard usage; the wheel is constructed on gun-carriage principles, and the tire of strong iron is put on hot, and chilled on tight, so that the structure is firm in the extreme. The Surveyor General of India has also invented an instrument running 20 miles on the same principle and graduated decimally, which is much approved of; the errors of perambulators should always first be tested by running them along one or two sides of a large triangle of the Trigonometrical Survey and comparing the values.

We have already described (page 251) the usual method of surveying a road, commonly called traversing; the same system precisely prevails for the illustration of the details on any line of country through which it may be required to carry a road, canal, or the like, and of which the general line, or the difference of latitude and longitude of various points is sought, care being taken to adopt as many checks as possible during the progress of the survey to prevent errors, viz., by different parties running independent routes and closing on each other's work every day, or by reverse operations, and by intersections at every convenient station; for the several bearings on the same object should, in the plotting, meet at a common point of intersection. These, and astronomical observations, are the only means by which a route survey can be checked. The method of plotting a survey or that of protraction by co-ordinates, has already been shown (page 287,) and the manner of adapting this for routes, cannot be better explained, than by transcribing an excellent example from Captain Boileau's Traverse Tables.

“ The annexed Table contains an extract from a survey, by myself, of the road between HATRAS and BAREILLY, in the N. W. Provinces of the Bengal Presidency, made in the year 1836, and will serve to illustrate the application of the Tables (Note page 289) to this kind of work. The first column refers to the numbers of the stations ; the second, the names of the villages or towns immediately contiguous to the lines, or through which they may pass, and prevents the necessity of frequent reference to the Field-book ; in the third column are entered the true bearings as registered on the limb of the theodolite, *i.e.*, the observed magnetic bearings, corrected for the variation of the compass ; columns four to the end are, in all respects, similar to those in the Table (page 301) and are filled up as directed for them.

“ The differences of latitude and the departures in the column of remarks entered against the last Station in each series, are computed from Table (C) in the Appendix, and serve to determine the relative geographical position of those Stations with reference to the first, or to any other Station in the series. The positions of places in maps are determined by similar entries, and are set off by scales of minutes and seconds from meridians upon parallels of latitude, in the same manner as the Stations in the adjoining diagram were by scale of miles and parts. Thus, if it were required to lay down the position of Duriapoor in a map of India, the latitude and longitude of Hatras, the first Station in the survey being known, it would be done in the following manner :

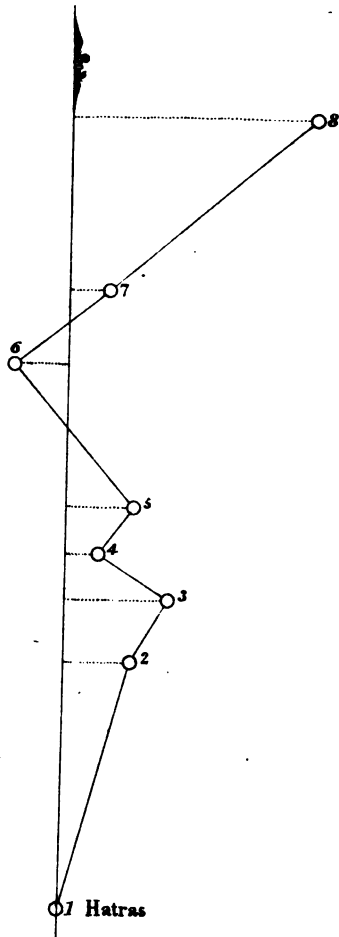
HATRAS, ...	Lat. N. 27° 36' 00"	Long. E. 78° 04' 00"
Duriapoor, ... diff.	Lat. N. 02 49·4 diff.	Long. E. 04 01·08 .
<hr style="width: 50%; margin: 0 auto;"/>		
Duriapoor, ... true	Lat. N. 27 38 49·4 true	Long. E. 78° 08 01·08
<hr style="width: 50%; margin: 0 auto;"/>		

“ With the true latitude and longitude so found, the position of the village would be fixed by the intersection of co-ordinates from the nearest meridian and parallel of latitude on the

map, and the position of any other point or place in the survey would be laid down in a similar manner."

For the purpose of finding the equivalent values of latitude and longitude *in arc*, *i. e.*, in degrees, minutes and seconds, from the Tabular traverses expressed in units of linear measure, Table (C) in the Appendix is given, and the following remarks, to exemplify the process in performing this reduction, and the principles on which such reductions depend, are likewise borrowed from the same author.

"In the explanation of the adaptation of Traverse Tables to surveying, the surface of the earth within the limits of each set of operations, has been considered as a plane, and the meridians as parallel straight lines; the relative lengths of the distance, difference of latitude, and departure, have been stated, not only to be accurately expressed by the three sides of a right-angled plane triangle, but to be truly projected by the construction of that triangle upon the map; both of these statements are, conformably with the hypothesis, strictly true, and boundary surveys, or indeed maps of small extent, may be projected with sufficient accuracy for all practical purposes by the rules given in the text. In route surveys, also, where the general line lies



near to a meridian or parallel of latitude, the results so obtained approximate very nearly to the truth; but where a considerable extent of country has to be mapped, or where the general line of a survey traversing the meridians at an oblique angle has to be represented, we are compelled to abandon our hypothesis,—the convergence of the meridians being sensible in extensive maps on any part of the earth's surface, but in a much greater degree in the higher latitudes than near to the equator: therefore, while we may still consider each individual Station to be correctly projected by the intersection of co-ordinates from the nearest meridian and parallel of latitude on a map, if we only take the necessary precaution in the field of correcting our bearings, whether true or magnetic, by observation, as often as the inclination of the meridians becomes sufficient to require it to be done,—still, a correction will be necessary to convert the departure between any two distant Stations, as obtained by the Traverse Tables, into the equivalent difference of longitude *in arc* between the same places. A similar correction would be necessary in the Tabular differences of latitude, but that the variation in the length of those degrees of latitude lying near to each other is so small as to be incapable of representation, excepting in maps of very large scale, and extending over great portions of the earth's surface.

“ To obtain the difference of latitude and the departure for any bearing and distance, with perfect accuracy, by the Traverse Tables, it is essential that the distance should be an oblique rhomb line; *i. e.*, a portion of a spiral cutting all the meridians over which it passes at the same angle; but where the lines are so short, as in a survey is generally the case, the difference between the lengths of a straight line, a circular arc, or a rhomb line, drawn between any two Stations, is inappreciable, and we may therefore consider our Station lines as so many rhomb lines; and, consequently, the difference of latitude and the departures between any two distant places, as deduced from the

intermediate lines in a survey, to be the same as if it had been obtained from a rhomb distance measured between those places.

“The departure and difference of longitude have, in the rules given for applying the Traverse Tables, been considered as identical; and this also, conformably with the hypothesis above-mentioned, is strictly the case. The meridians are not, however, really parallel, though within short distances they may be so considered in practice, but converge towards the poles (Note page 273); and the degrees of longitude, instead of being equal, as they are assumed to be in the theory of the parallelism of the meridians, decrease in the same direction; therefore the departure and difference of longitude cannot any longer be considered as identical; for an equal amount of departure, *i. e.*, the same number of linear units, will measure different arcs of longitude according to the distance from the equator at which the departure may be reckoned. Thus, at the equator, a departure equal to 6086 feet, measures one minute of longitude, whereas at 89° it measures nearly a degree, and proportionally at all intermediate stages. In measuring an oblique distance, therefore, it is evident that, supposing the distance to be divided into a number of infinitely small parts or increments, the amount of departure due to each increment ought to be reckoned in arc of longitude at its own distance from the equator, and that the departure for the whole distance, when converted into longitude, will equal the sums of all the elementary arcs of longitude of each increment in the distance. On moving from the equator towards the poles, these elementary arcs will be continually decreasing, and the contrary in travelling from the poles towards the equator; but there will be a certain point between the two extremities of each distance, or a certain *mean parallel of latitude*, upon which, if the *whole* departure be reckoned, it will express the true difference of longitude between the two extremities of that distance. This mean parallel is always higher than the *middle* parallel between those extremes, but in the construction of maps, where the measured distances are

short, and the intervals between which the reduction of departure into longitude takes place are small, it will give results sufficiently near to the truth if we reckon the departure upon the *middle* parallel between the two extreme points of any distance.

“If the figure of the earth were truly spherical, all degrees of latitude would be equal, while the degrees of longitude would decrease in the direct ratio of the cosine of the distance from the equator; but, owing to the spheroidal figure of the earth, the degrees of latitude are not equal, but increase from the equator to the poles, the degrees of longitude decreasing in that direction in a ratio slightly different from that mentioned above. The greatest difference between any two successive degrees of latitude, which occurs about 45° from the equator, is 63 feet, or 1.05 feet in one minute, being rather less than 11 inches in one mile. This difference decreases both towards the equator and poles, and is too small to require the attention of the practical man, unless when his operations extend over a surface of many degrees: but in longitude the difference increases from 56 feet between the equatorial and first degrees, to 6393 feet at the poles; and, therefore, though not very sensible at first, it soon becomes so, even through the minutes and seconds of each degree.

“I shall now show the use and application of Table (C) in the reduction of traverses, taking as examples the reductions entered in the column of remarks in the Table at page 362.

“*Example.* Required the difference of latitude and of longitude *in arc* between Hatras and Duriapoor, and the true latitude and longitude of the latter place, the Tabular traverses being N. 3 M. 1 Fur. 919.8 Lks., and 4 M. 0 Fur. 863.6 Lks. E.; the latitude of Hatras being N. $27^\circ 36'$, and its longitude $78^\circ 04' E.$

“Reduce the Tabular traverses to feet: divide the Tabular difference of latitude so reduced by the value of one minute or second of latitude in a line with the number corresponding nearest to the latitude of the starting point, in the column

designated "distance from the equator;" and the quotient will be the difference of latitude required *in arc*. Add to, or subtract this difference from the latitude of the starting point, according as it may be of the same or of a different denomination, and it will give the true latitude of the place required. Take the middle latitude between the starting point and that for which the difference of longitude is required, and correct the value of one minute or second in the Table, for the number in the column designated "distance from equator," corresponding nearest to that of the middle latitude. Divide the Tabular difference of longitude reduced to feet by the corrected value of one minute or second, and the quotient will give the difference of longitude *in arc* required; which being added to, or subtracted from, the longitude (from Greenwich) of the starting point as above, will give the true longitude of the place required.

	Feet.		Feet.
Three miles... ..	5840	Four miles	21120
One furlong	660	863 links (Table D) ..	569·58
919 links (Table D) ..	606·54	·6 ditto, (ditto)	·396
·8 ditto, (ditto)	528	Reduced diff. long. .	21689·976 E.
Reduced diff. lat. . N. 17107·068			

Lat. of Hatras N. $27^{\circ} 36'$; value of 1' of lat. for 28° , in Table C = 6059·1 and $17107·068 \div 6059·1$ gives $02·8233'$, or N. $02' 49·40''$, nearly, for the diff. of latitude *in arc*, which added to the latitude of the starting point (being of the same denomination) gives N. $27^{\circ} 36' + N. 02' 49·40''$, or N. $27^{\circ} 38' 49·40''$ for the true latitude of Duriapoor.

Again, for the difference of longitude in arc :

Latitude of Hatras	N. $27^{\circ} 36'$
Half diff. of lat. of Duriapoor	N. $01·41167$
Middle latitude	N. $27^{\circ} 37·41167$
Value of 1' of longitude for 27° , Table C.....	$5426·2$
Ditto	28° , ditto
	$5377·3$
Difference for 1°	— $48·9$

Now 1° , or $60'$: — $48\cdot9$ feet :: $37\cdot41167'$: — $30\cdot49$, and $5426\cdot2 - 30\cdot49 = 5395\cdot71$ feet, value $1'$ of longitude to middle latitude: then, using this number as a divisor, we shall have the tabular difference of longitude reduced to feet $21689\cdot976 \div 5395\cdot71 = 4\cdot018'$, or $04' 01\cdot08''$ E., the difference of longitude *in arc*, which added (as above) to the longitude (east of Greenwich) of Hatras ($78^\circ 04'$) gives $78^\circ 08' 01\cdot08''$ E. for the true longitude of Duriapoor."

The latitude should be found by celestial observation at least once in twenty-four hours, and if the meridian altitude of the sun be within range of the instrument it should not be neglected, but the true observation to trust to, is the latitude by night from Stars North and South, which in a fine climate can nearly always be obtained, and the difficulty of measuring the altitude in low latitudes, when the double angle is larger than a sextant can measure, avoided. A sextant of five or eight inches radius and artificial horizon, are the only safe instruments, but these, of course, are useless for the meridional altitudes of the sun in low latitudes.

The determination of the longitude of a place requires more knowledge than is requisite to find its latitude. No pains should be spared, nor any time be considered misspent in endeavouring to fix accurately the chief points in a country by independent observations for longitude. The only trustworthy method for a locomotive observer is by occultations. One good observation of an occultation is worth fifty observations depending on the moon's motion; lunar distances are not to be relied on within 20 miles. Moon culminating stars, which is a favorite method, requires a long series of observations, and the fixing the transit instrument takes several days, and the method depending on the moon's motion, the error is magnified twenty-eight times in the result. Eclipses of Jupiter's Satellites are unsatisfactory on account of the Penumbra. Unfortunately occultations occur very seldom and give a great deal of trouble, but the observa-

tion when made is very valuable and ought to be good within 2,000 or 3,000 feet at the outside, so that a couple of occultations is sufficient for a good approximation. It is also advisable that corresponding observations at an observatory, should, if possible, be made. Chronometers are not to be trusted, for long circuitous journeys, especially in a meridional direction.

“ The above methods which are fully treated of in Part V, will enable the observer to fix the longitude of a place *absolutely*, that is to say, independently of the transport of time by a watch or chronometer, but for short distances this instrument will be perfectly serviceable, and connect one place with another, so that all may be *relatively* right in a map of the country, though *absolutely* wrong ; and when at any subsequent opportunity the longitude of any one point may be correctly determined, all will move together in its right place.

“ With regard to the management of a chronometer, the great point is to find its *error* at any place, the longitude of which is known, and its *rate* whenever an opportunity is afforded, by stopping two or three days in any place, and to make allowance for any alteration in rate over the whole route travelled since its rate was last determined.

“ The mode of finding the longitude before described, by keeping an exact itinerary of the courses by the compass and the distance travelled, corrected for variation, and checked by observations for latitude, is the simplest, and will give a very fair approximation, and this method should never be neglected, as it will serve as a useful check to astronomical observations.

“ By these means a careful and industrious traveller can hardly fail of obtaining abundant materials for the correct laying down of his route, and should he traverse the country in different directions, he will thus have a number of lines crossing each other forming a route map, from which for want of a regular survey, a very fair idea of the country may

be gleaned, particularly when such map is accompanied by a detailed description. Another essential object to which we would call the traveller's attention is, never to go to sleep until he has mapped his day's route, and written up his journal from the notes of the day."*

To shew the accuracy with which this description of survey may be carried out, we subjoin an account of the Ray Trace System as pursued in the Great Trigonometrical Survey and detailed in the following Chapter.

* "What to observe, or the Traveller's Remembrancer." By J. R. Jackson.

CHAPTER XV.

ON THE RAY TRACE SYSTEM OF THE GREAT TRIGONOMETRICAL SURVEY.

ANALOGOUS to the route survey, is the Ray Tracing System introduced by Lieutenant Colonel Everest, the late Surveyor General of India, and described (page 19) in his account of the "measurement of two sections of the meridional arc of India," published in 1847. This is most useful, where it is necessary to know the exact line between two places for road making, or the proper direction in which to lay the telescope for observing the Blue Light Signals, which are burned by sets of four, at ten minutes interval between each lighting, and which are scarcely in a single instance, during the whole of the operations of the Great Trigonometrical Survey visible to the naked eye. Without calculating this direction beforehand, it would be impossible to say, in the side of a triangle, perhaps 10 to 15 miles, how the ray would fall, and which identical trees would require to be felled. For this purpose a minor series of triangles, or a simple route, is carried on along the ray, commencing from the station of the eye and terminating at that of the object, wherein by assuming the most commodious of the first two sides as unity, and as the line of direct co-ordinates, it is easy to compute not only the angle which the ray makes with this line, but also the ratio, which they bear to each other.

The following directions, computation and example of a ray trace, have been drawn up in conformity with these principles,

and are precisely those at present employed in the Great Trigonometrical Survey of India. Most of the rays for the principal triangles have been worked out in this manner, whence the method, whether executed by minor triangulation, or perambulator measurement, has derived the name of "Ray Tracing," and affords ample opportunities for filling in topographical details, and fixing the secondary points, within large triangles.

Every Route Survey, conducted on the principles of the Ray Trace, should, if possible, originate in a point previously determined by a Trigonometrical Survey; when a fixed point of this kind is not available, the origin of the route should be placed on some permanent object, such as a mosque, a temple, a church or a pukka building, &c., the position of which can be readily ascertained whenever required, by a trigonometrical operation.

In a Route Survey, the measurements required consist of two parts, viz., linear and angular. The measurements of the former kind are usually made with a perambulator, and those of the latter are invariably executed with a theodolite; the angular measurements are much less liable to error than the linear measurements; whence the corrections arising from all and every discrepancy exhibited by a Route Survey, are exclusively applied to the measured distances, thereby leaving unaltered the observed angles which are considered errorless; on this assumption is based the common method for computing and reducing a Route Survey.

After the origin of the survey has been determined upon, the Surveyor proceeds forward and selects stations in the route; the conditions to be attended to in this operation are, 1st, the reciprocal visibility of the adjacent stations, and 2nd, the eligibility of the intermediate ground for a perambulator measurement.

In closing the operation, it must terminate also on a point which has been either determined trigonometrically, or which is capable of being so determined in future.

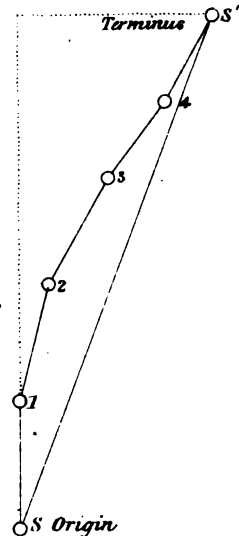
When the origin and terminus of a Route Survey are fixed points, any error committed in the execution of the work, is susceptible of easy elimination as will afterwards appear.

After the Stations are selected, the next thing is the measurement of the distances and angles. For this purpose, a reading of the perambulator at the origin is taken, and then it is rolled forward in a straight line to $\odot 1$, where a second reading is taken; here likewise the theodolite is adjusted, and the angle between the origin and $\odot 2$ observed; this observation should be repeated on both faces of the instrument; the advantages attending the taking of this double observation are these: In the first place the record is checked, and secondly, any error induced in the individual observations by the unadjusted line of collimation, or the dislevelled transit axis, disappears in the mean value thereof.

After $\odot 1$ is disposed of, the Surveyor proceeds to $\odot 2$, where he takes observations similar to those made at $\odot 1$; the remaining stations of the route being treated in like manner, he will at last arrive at the terminus, where having no angle to observe, he will only note down the reading of the perambulator; after the completion of the field measurement, the computation of the route is made, the principles and method of executing which may be explained in the following manner:

On reference to the diagram in the margin, it will be perceived that if the first line (origin to $\odot 1$) be extended so as to meet the perpendicular drawn thereto from the terminus, the lengths of these two lines being known, all the other elements of the route are ascertained by a very easy computation.

For instance, calling y the perpendicular above mentioned, and x the line drawn from the origin to meet it, $\odot S$ Origin



$\frac{y}{x} = \tan \theta$, θ being the angle at the origin between $\odot 1$ and the terminus.

Again, the whole distance from the origin to the terminus of the route is equivalent to $\rho = x \cdot \sec \theta$.

The use of these elements for correcting the measured distances of the route, and for laying off the direct line from the origin to the terminus, will be shown presently.

In the computation of a Ray Trace Survey, it should be premised that x is taken as the axis of the direct, and y that of the perpendicular co-ordinates.

Besides x and y , there are other symbols required to designate the measured distances and angles, and the characters usually made use of for this purpose are as follows:

Distance	Origin to $\odot 1 = a$
Ditto	$\odot 1$ to $\odot 2 = a$
Ditto	$\odot 2$ to $\odot 3 = b$
Ditto	$\odot 3$ to $\odot 4 = c$

.....

Again,

Mean observed angle	at $\odot 1 = \odot 1$
„	„ Ditto at $\odot 2 = \odot 2$
„	„ Ditto at $\odot 3 = \odot 3$

.....

These observed angles are deduced by subtracting the reading of the rear station from that of the forward point, and consequently they may be of any value whatever from 0° to 360° .

From the observed angles deduced as directed above, let the following arcs called angles for computation be computed.

A	= $\odot 1$
B	= A + $\odot 2 - \pi$
C	= B + $\odot 3 - \pi$
D	= C + $\odot 4 - \pi$

.....

That is to say, the angle for computation at any station is equivalent to the observed angle, augmented by the last angle

for computation, and diminished by 180°;* the angles for computation as deduced above are those at which the lines a, b, c, \dots are inclined to the first line a , or to the parallels thereof.

After the deduction of the angles for computation, it is necessary to calculate the following terms :

$$\begin{aligned} x' &= a. \cos A & y' &= a. \sin A \\ x'' &= b. \cos B & y'' &= b. \sin B \\ x''' &= c. \cos C & y''' &= c. \sin C \end{aligned}$$

$x', x'', x''' \dots$ are called direct co-ordinates, they being the projections of a, b, c, \dots on the axis x ; similarly $y', y'', y''' \dots$ being the projections of the same lines on the axis y , are called perpendicular co-ordinates; the signs of these co-ordinates depend upon the magnitude of the angles from which they are respectively derived, and these signs will be readily found by a reference to the following Table :

Table exhibiting the Signs of the direct and Perpendicular Co-ordinates.

Magnitude of the angles for computation.	Signs of the Co-ordinates.	
	Direct.	Perpendicular.
Quadrants.		
1st.	+	+
2nd.	-	+
3rd.	-	-
4th.	+	-

After affixing proper signs to the direct and perpendicular co-ordinates, collect the former into one sum and the latter into another; the former of these sums augmented by the first distance (a), is the numerical value of x , while the latter sum is the numerical value of y .

After the values of x and y are determined, θ and ρ may be deduced by the following formulæ.

$$\text{Tan } \theta = \frac{y}{x}; \quad \rho = x. \sec \theta.$$

Now $\angle \theta$ is of the same sign with y , and may be either positive or negative. In the former case, the terminus is to the right and in the latter to the left of $\odot 1$; knowing the value of

* The established symbol for a semicircle or 180° is π .

θ , as likewise its position with respect to $\odot 1$, it is easy to trace the direct line of the route. For this purpose, put up the theodolite at the origin and take a reading to $\odot 1$. To this reading apply, according to its sign, the $\angle \theta$; the resulting reading or the telescope set thereto, will point to the terminus of the survey.

Again, if it be required to trace the route from the terminus, it may be done thus: According as θ is positive or negative add it to, or subtract it from, π . From the sum or difference so obtained, (augmented when less than the subtractor by 2π) deduct the last angle for computation, the remainder will be the $\angle \theta'$ at the terminus between the origin and the last station of the route. The $\angle \theta'$ may be of any value from 0° to 360° ; it is likewise always positive. Adjust the theodolite over the terminus, and take a reading to the last Station; to this reading add the $\angle \theta'$: the resulting reading will be the required direction of the origin from the terminus.

It is evident that ρ , determined as directed above, is in terms of the perambulator, calling R the value of the same distance as derived from a trigonometrical operation, it follows that $\rho \propto R$ is the error of the Route Survey.

Without making any assumption as to the cause of this error, it is evident that this discrepancy must be expunged, before the details furnished by a Route Survey can incorporate with those of a trigonometrical operation.

The simplest and perhaps the only method of performing this, is by the following rule of proportion.

- As the direct perambulator distance of the route (ρ)
 : The trigonometrical value thereof (R)
 :: Each measured perambulator distance
 : Its corresponding trigonometrical length.

Correcting by this proportion all the perambulator distances, as well as all the co-ordinates deduced therefrom, the resulting elements will obviously be in terms of the unit of the Trigonometrical Survey.

The following is an example of the field notes and computation deduced therefrom.

SPECIMEN OF THE RAY TRACE SURVEY FIELD-BOOK.

TRACING OF RAY DONAO TO KAINKERA, 10TH AND 11TH NOVEMBER, 1842.

Route Survey by LIEUT. A. S. WAUGH, with 7-inch Theodolite B, No. 12, and Perambulator No. 2, with 6 mile Dial.

Station of Observation.	Objects Observed.	Face	Vernier Readings.				Angles deduced.		Perambulator.		Remarks.
			A	B	C	Mean.	One reading.	Mean.	Readings.	Distances.	
Donao, .....	.....	...	.....	.....	.....	.....	.....	.....	.....	1-964	
⊙ 1 near ... Manjulia,	Mag. north, Donao, ... ⊙ 2	L	0 0 0 314 11 0 132 24 0	..... 10 30 23 30	..... 10 30 23 45	..... 314 10 40 132 23 45	..... 178 13 5 178 13 40	..... .....	..... .....	3-039 1-075	
Donao, ... ⊙ 2	Donao, ... ⊙ 2	R	134 9 15 312 23 45	9 15 23 15	9 10 23 15	9 10 23 25	178 14 15 .....	.....	.....
⊙ 2 near ... Bikaripur, ...	Mag. north, ⊙ 1 ... ⊙ 3	L	0 0 0 312 10 0 130 37 0	..... 9 15 36 45	..... 9 30 36 45	..... 312 9 35 130 36 50	..... 178 27 15 178 27 23	..... .....	..... .....	6-251 3-212	
.....	.....	R	132 8 45 310 36 45	9 0 36 0	9 0 36 30	8 55 310 36 25	178 27 30 .....	.....	.....
⊙ 3 near ... Simeria,	Mag. north, ⊙ 2 ... ⊙ 4	L	0 0 0 310 36 45 121 35 30	..... 35 30 35 30	..... 36 15 35 15	..... 310 36 10 121 35 25	..... 170 59 15 170 58 49	..... .....	..... .....	1-432 1-181	
.....	.....	R	130 41 45 301 40 15	41 45 39 50	41 40 301 40 2	41 40 0 2	170 58 22 .....	.....	.....

TYPE OF CALCULATION OF RAY DONAO TO
KAINKERA.

DISTANCES.	OBSERVED ANGLES.
Donao to ☉1 = 1·075 = a	At ☉1 = 178 13 40
☉1 to ☉2 = 3·212 = a	☉2 = 178 27 23
☉2 to ☉3 = 1·181 = b	☉3 = 170 58 49
☉3 to ☉4 = 1·606 = c	☉4 = 185 26 43
☉4 to ☉5 = 1·767 = d	☉5 = 215 54 0
☉5 to ☉6 = 0·895 = e	☉6 = 184 0 5
☉6 to ☉7 = 0·707 = f	☉7 = 155 22 13
☉7 to Kainkera = 1·122 = g	

Hence the Angles for Computation are—

A = 178 13 40		
B = (178 13 40 + 178 27 23 - π) = 176 41 3		
C = (176 41 3 + 170 58 49 - π) = 167 39 52		
D = (167 39 52 + 185 26 43 - π) = 173 6 35		
E = (173 6 35 + 215 54 0 - π) = 209 0 35		
F = (209 0 35 + 184 0 5 - π) = 213 0 40		
G = (213 0 40 + 155 22 13 - π) = 188 22 53		
A = 178 13 40 Cos. 9·99979		Sin. 8·49033
a = 3·212 Log. 0·50678		Log. 0·50678
	<u>0·50657</u> ... + 3·210	<u>2·99711</u> ... - 0·099
B = 176 41 3 Cos. 9·99927		Sin. 8·76223
b = 1·181 Log. 0·07225		Log. 0·07225
	<u>0·07152</u> ... + 1·179	<u>2·89448</u> ... - 0·068
C = 167 39 52 Cos. 9·98986		Sin. 9·32968
c = 1·606 Log. 0·20575		Log. 0·20575
	<u>0·19561</u> ... + 1·569	<u>1·53543</u> ... - 0·343
D = 173 6 35 Cos. 9·99685		Sin. 9·07907
d = 1·767 Log. 0·24724		Log. 0·24724
	<u>0·24409</u> ... + 1·754	<u>1·82631</u> ... - 0·212
E = 209 0 35 Cos. 9·94178		Sin. 9·68570
e = 0·895 Log. 1·95182		Log. 1·95182
	<u>1·89360</u> ... + 0·783	<u>1·63752</u> ... + 0·434

F = 213 0 40	Cos. 9.92354	Sin. 9.73624
f = 0.707	Log. $\bar{1}.84942$	Log. $\bar{1}.84942$
	$\bar{1}.77296 \dots + 0.593$	$\bar{1}.58566 \dots + 0.385$
G = 188 22 53	Cos 9.99534	Sin. 9.16364
g = 1.122	Log. 0.04999	Log. 0.04999
	$0.04533 \dots + 1.110$	$\bar{1}.21363 \dots + 0.164$
a =	$\dots + 1.075$	
Sum of Direct Co-ordinates	$x = \underline{+11.273}$	Sum of Perpendr. Co-ordinates $y = \underline{+0.261}$
Sum of Direct Co-ordinates	$x = 11.273$	Log. $\bar{1}.05204$
		A. C: 8.94796
Sum of Perpr. Co-ordinates $y = 0.261$	Log. $\bar{1}.41664$	
$\theta = + 1^\circ 19' 35'' \dots \dots \dots$	Tan. 8.36460	Cos. 9.99988
		Sec. 0.00012
Sum of Direct Co-ordinates $x = 11.273$		Log. $\bar{1}.05204$
Distance by Perambulator measurement		Log. 1.05216
Ditto Triangulation.....		Log. 1.04716
Constant Log. of Correction		Log. $\bar{1}.99500$

This constant logarithm added to the logarithms of the perambulator distances will furnish the logarithms of the same distances in terms of the unit of the Trigonometrical Survey.

θ' COMPUTED.

	$\pi + \theta$	=	181	19	35
Which being less than subtractor is augmented	}	=	541	19	35
by 2 π , and becomes,					
Deduct G or last \angle for computation,					
	Hence, ... θ'	=	<u>352</u>	<u>56</u>	<u>42</u>

The following is the method of computing a Ray Trace Survey without the aid of the trigonometrical distance, where-with it is connected.

The method just explained for the computation of a route survey, requires a previous knowledge of the distance of S

to S^1 ; but it sometimes happens in practice that this information is not forthcoming and cannot be ascertained without a tedious computation, in which case, the following method of deduction should be adopted, which determines the true positions of the Route Survey points, without reference to the direct distance between the two trigonometrical Stations, wherewith they are connected.

In the diagram (page 374) S and S^1 are two trigonometrical Stations, and $\odot 1$ $\odot 2$ $\odot 3$ are points of a Route Survey, which originates in S and terminates at S^1 .

The elements supposed to be given are the latitude and longitude of S and also the azimuth of $\odot 1$ from S .

With the perambulator distance S to $\odot 1$ and the elements above given, deduce the latitude and longitude of $\odot 1$, as also the back azimuth of S ; with the back azimuth of S and the observed angle at $\odot 1$, compute the forward azimuth of $\odot 2$ from $\odot 1$; with this azimuth again, and the given perambulator distance $\odot 1$ to $\odot 2$, deduce the latitude and longitude of $\odot 2$; by a similar process, the latitudes and longitudes of the other points of the Route Survey, as likewise of trigonometrical Station S^1 may be derived.

When the computation arrives at S^1 , the deduced latitude and longitude of this Station will probably differ from their respective trigonometrical values; the discrepancies thus displayed present, under an accumulated form, the whole error of the survey. To eliminate this error: add all the perambulator distances together, and take the logarithm of the sum; to the arithmetical complement of this logarithm, add the log. of the error in latitude, the sum will be a constant log.; to this constant log., add separately and in the order in which they stand, the logs. of the several perambulator distances of the survey, and find the natural numbers corresponding to these sums: now the correction for the first Route Survey point is the first natural number; the correction for the second point is the sum of the first and second natural numbers; simi-

larly the correction for the third Route Survey point is the sum of the first three natural numbers; and in the same manner, the correction for the other points, and also that for trigonometrical Station S^1 may be deduced.

It is evident, that the deduced correction for S^1 ought to be identical with the whole error exhibited by the survey, and when this takes place, the computation of the corrections may be assumed as having been correctly performed; in this computation the logs. used should be carried to five decimals, and the natural numbers deduced should be limited to a tenth of a second.

The error in longitude may be corrected in the same way as that in latitude; this mode of dispersing the error of a Route Survey is likewise applicable when the positions of S and S^1 have been fixed by astronomical observation.

The method of carrying out the Ray Trace System by minor triangulation will be treated of in a subsequent Chapter.

CHAPTER XVI.

ON TRIGONOMETRICAL SURVEYING, AND THE MODE OF OPERATIONS TO BE PURSUED IN HILLY COUNTRIES.

IN the system of survey which has been described in the last few chapters, shewing the style of a Revenue Survey, which embraces all villages situated in a champaign or well-cultivated country, the relative positions of the several Stations are ascertained by direct *linear-measurement*, but in a less favored, or mountainous and densely-wooded country, where, on account of the inequalities of surface, the measurements are liable to more than ordinary errors, and to connect the measurement of one village with another, with any degree of expedition, is almost rendered impossible, it is necessary, in order to prevent accumulation of errors, that the detailed measurements be based on an accurate system of triangulation.

To pursue a Topographical Survey of countries of the above description, which latterly have been met with to a considerable extent in the course of the Revenue Operations in India, a Trigonometrical Basis becomes essential, we therefore propose to enter into such details for the prosecution of a Trigonometrical Survey, founded on the principles and system as now actually in use, as will enable the Surveyor to prepare himself for every emergency, for all surveys executed without due regard to this precaution, however carefully the details may be performed, partake of the character of detached operations, which are incapable of union *inter se*, or of harmonious combination with other surveys.

Base Line.

All Trigonometrical Operations emanate either from some actually measured line, called a *Base Line*, or from a side of some other Trigonometrical Survey, the length of which is known by calculation. As a general rule, for all surveys of a secondary order, the measurement of a base should never be attempted, if by any possibility the side of a triangle of the Great Trigonometrical Survey, can be obtained, and it will be found preferable to go a little out of the way to secure this, and to perform a little extra triangulation, in consequence, than to spend time on so difficult and tedious a task, as the measurement of a base, with rude and imperfect instruments, the results of which will never equal the value of a computed side, deduced with the scrupulous care and nicety of an important Trigonometrical Survey.

The measurement of a Base Line, from which the sides of the triangles of an extensive series are to be calculated, such as for the measurement of an arc of the meridian, although apparently easy, is the most difficult and important part of a Trigonometrical Survey, as upon its accuracy, that of every triangle depends, and one in which every refinement, which mechanical ingenuity can devise, has been adopted, with a view to obtain Mathematical accuracy. The length of the base is made to depend in general on the proposed length of the sides of the triangles, which are to be deduced from it, but circumstances seldom allow it to exceed from seven to eight miles in extent, as its position is to be selected on an even plain, as nearly as possible horizontal, and otherwise conveniently adapted for purposes of measurement, where both ends of the base would be visible from each other, as well as from such stations with which they should form Symmetrical Triangles.

Our limits will not admit of entering into a description of the different implements, which have at divers times been made use of for the measurement of a Base Line. Formerly

in the English, as well as in the Indian Trigonometrical Survey, Steel Chains of one hundred feet in length were employed in this operation, but this implement has now been set aside, and the apparatus introduced in its place are the Compensation Bars and Microscopes. On the Continent, rods of different metals, as platina, copper, iron, &c., are used in measuring a Base Line.

When a Base Line is measured with a Metallic Rod or Chain, it will stand in need of a correction dependant upon temperature, because the length of the measuring implement varies with the indications of the Thermometer. When the Compensation Bars and Microscopes are employed, the correction for temperature is never required, that apparatus being so constructed, as to indicate the same, or nearly the same length, under every variation of temperature.

Full accounts of the measurement of the Base Line, with Compensation Bars and Microscopes, will be found in Everest's Account of the Measurement of the Arc of the Meridian, 1847, and in Yolland's Ordnance Survey, 1847. Again, Lambton's Papers in the Asiatic Researches, as likewise Everest's first work on the Indian Arc, published in 1830, contain accounts of Base Lines measured with a Steel Chain. But the paper which would be most serviceable to a Revenue Surveyor is that published by Captain Herbert, in the 14th volume of the Asiatic Researches, in which he gives an account of the measurement of a Base Line, executed with deal rods in the Dehra Dhoon, for the purpose of making a Trigonometrical Survey of the Himalyah Mountains.

The method of laying out a Base Line previous to measurement is thus done. A *Boning* instrument,* or in lieu thereof a Theodolite, being firmly planted at the origin, its line of

* The *Boning* Instrument is used only for Base Line operations, it has the common properties of the Theodolite, only with more perfect adjustments to the line of Collimation and of the Horizontal and Transit Axis Levels, and in addition *lateral* motion to the Telescope.

collimation and the transit axis being likewise truly adjusted; marks are then fixed in the ground, at different distances in a continuous vertical plane, as far as the power of the Telescope will permit, the instrument is then taken forward to within three or four marks, or pickets of the extremity of the line ranged, and placed correctly over one of them by means of the plummet, and by the intersection of the cross-wires of the Telescope, directed to the back and forward pickets successively. This done, other marks are then fixed in the same vertical plane until the terminus of the Base Line is reached.

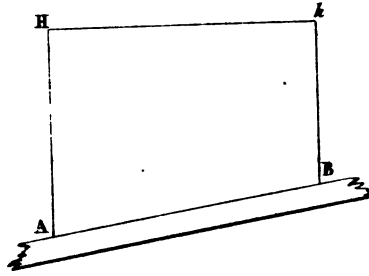
Boards 12 or 15 inches square, with concentric black and white rings painted on both sides, make good ranging marks. Besides the marks at the extremities of a Base Line, which should always be constructed so as to be *permanent*, two or three intermediate points should be carefully determined and marked, during the progress of the measurement, so as to serve for testing the accuracy of the different portions, by comparing them with each other by minor Triangulation.

In measuring a base for the Topographical Survey of any moderately-sized portion of country, it will be sufficient to measure its length carefully two or three times with well seasoned fir or teak rods, or a good Steel Chain which has been compared with a standard.

The rod or chain employed in the operation should be always, if possible, adjusted to a horizontal position; but this is a condition which the unevenness of the ground would occasionally prevent its being carried into effect. When this occurs, the angle, at which the measuring implement is inclined to the horizon, should be carefully observed and registered in the Base Line book.

As the Theodolite is the only instrument which is likely to be at the disposal of the Revenue Surveyor, we will proceed to show how it may be employed in determining the angle abovementioned. The Theodolite being fixed at a convenient

spot in the allinement of the Base Line, adjust the Telescope, or rather the line of vision thereof, to a horizontal position. Let Hh represent this line. Also suppose AB to be the measuring implement, placed as will be required in the course of the mea-



surement. Now the lengths of the lines AH and Bh can easily be ascertained, by holding first at A , and then at B , a perpendicular staff, and marking thereon the points at which it is cut by the visual line of the Telescope. Calling m the former and n the latter of these lines, it is evident; firstly, that when m and n are equal, the measuring implement is horizontal; and secondly, that when this equality does not obtain, the implement in question is inclined to the horizon, the advanced end B being higher or lower than the rear end A according as m is greater or less than n .

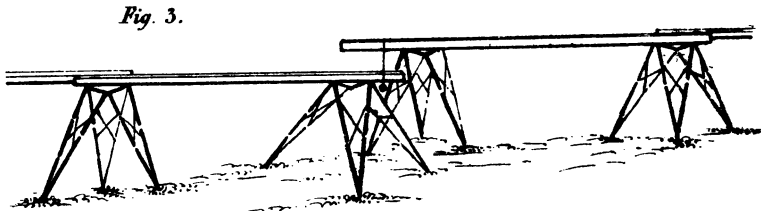
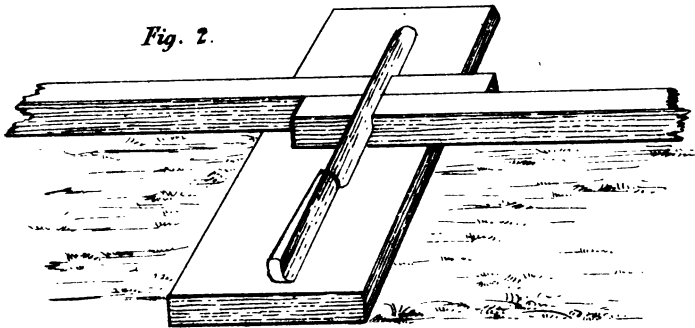
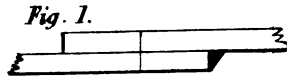
It is also clear that $\sin. i = \frac{m \oslash n}{h}$, in which i denotes the inclination of the measuring implement to the horizon, h being its length.

When the measuring implement is laid inclined to the horizon, the distance it measures off on the latter plane, is equivalent to its projection thereon. Putting $m \oslash n = d$ and $p =$ length of the projection abovementioned, we shall have $p = \sqrt{h^2 - d^2}$,

which expanded becomes $h - \frac{d^2}{2h} - \frac{d^4}{8h^3} - \frac{d^6}{16h^5} \dots\dots$

Compute therefore the terms $\frac{d^2}{2h}$, $\frac{d^4}{8h^3}$, $\dots\dots\dots$, and subtract their sum from h , the remainder will be the value of the projection of the measuring implement on the plane of the horizon.

A good method is to lay the pair of rods, as it is termed "in coincidence," that is, lines drawn across them near their extremities, are made to coincide most accurately as in the sketch (Fig. 1.) The ends of



the rods may be laid together on tripod stands, (Fig. 3,) a set of six being properly allined and levelled, and where the inequalities of the ground renders it necessary to alter the level, a plumb line is sufficient to obtain a coincidence of the marks on the rods. If the tripod stands are not available, boards may be laid down, the edge of a common table knife being placed along the divisions or cuts on the rods, to shew the coincidence, as in Fig. 2.

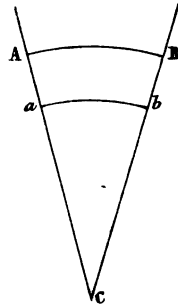
In order to compare together, and connect bases measured at different elevations in distant parts of the country, it is necessary that they be referred to a common elevation. For this common standard, the mean level of the sea, naturally presents itself as the most suitable, admitting, by its very nature and universal access, of easy reference.

A base measured on an elevated plain is thus reduced to its proper measure at the level of the sea.

Let r = radius of the earth (supposed to be spherical) at the level of the sea.
 $r + h$ = radius at the level of the measured base.

A = measured base AB

a = reduced base ab



Then because similar arcs are in the same ratio as their radii, we have

$$r + h : r :: A : a$$

which gives $a = \frac{r A}{r + h} = A \left(1 + \frac{h}{r}\right)^{-1}$ which expanded by common division becomes

$$A \left\{ 1 - \frac{h}{r} + \frac{h^2}{r^2} - \frac{h^3}{r^3} + \&c. \dots \right\}$$

$$\text{Therefore } a = A - \frac{Ah}{r} + \frac{Ah^2}{r^2} - \frac{Ah^3}{r^3} + \&c. \dots$$

Subtracting both sides of the equation from A , there will arise

$$A - a = \frac{Ah}{r} - \frac{Ah^2}{r^2} + \frac{Ah^3}{r^3} - \&c.$$

which is the required expression for the reduction of the measured line to the level of the sea, and in which it will never be necessary to use more than the first term.

As an example to illustrate this formula, we will take the Base Line measured by Col. Lambton, in 1815, in the Valley of Beder—

		Feet.		
Measured length of the Base Line	A =	30809.07	Log.	4.48868
Mean height of the base above the sea level,	} h =	1957.	Log.	3.29159
Mean radius of the earth, .....					r =	20888153.	Log. AC	8.68010
Required correction,		2.89		0.46037

which deducted from the measured base will give its length at the sea level.

Before, however, deducing the real length of the line, the manner of determining the length of the rods must be attended to. Twenty-five feet rods, about $1\frac{1}{4}$ inches by $1\frac{1}{4}$, have been made use of, and four rods placed together, compared with the Standard Chain. The graduation of one of these rods again may be made with a two-foot Gunter's Brass Standard Scale, and the other three compared with it, as a check on the operation; but such a length and thickness of rod require a large number of stands, or trestles to support it. For one pair of such rods, nine stands would not be too many, at a distance of $6\frac{1}{4}$ feet apart—twelve feet rods, therefore, may be deemed preferable. A good Beam Compass, with metal points, may be used for taking off the divisions, which should be laid down several times over by means of dots and arcs; studs of ivory having been for greater accuracy let into the wood, on which the arcs may be drawn; the beam should then a second time be compared with the scale, after the stepping, or dividing is concluded, and half the difference (if any) applied as a correction, the Thermometer being noted before and after the mean is taken. The two rods after being divided, must be duly compared with each other, being firmly tied together and laid on a smooth table, planed exceedingly true. The comparison with the Steel Chain requires, that the

latter should be fairly stretched with a weight of about 19 lbs., and due allowance made for the expansion of the metal, which has been found to be .0075 inches for every 1° of Fahrenheit on 100 feet. The employment of the Chain in measuring a Base Line not only occupies an immense period of time in the operation itself, but still more so in the preparation of coffers and stands, which latter require elevating screws and are not to be made without extreme difficulty, in most of the situations, in which Surveyors find themselves in this country. An expeditious method, and one requiring hardly any apparatus, is to drive stout pickets into the ground at distances of twelve feet, and with a rod of this length well trussed and furnished with points, forming in some measure, a large Beam Compass, the exact length may be set off from picket to picket. The measurement being conducted so near the ground, occasions however great uneasiness in the position, and it is well known how essential an easy position is, to correct operations of every kind, the plan may, nevertheless, be found useful, where only a tolerable degree of exactness is necessary.

The Base Line, determined as described above, may be made the origin of a series, or of a network of triangles as may be required. After the Triangulation has traversed over a certain extent of country (say 150 or 200 miles) one of the computed distances, when conveniently situated for the purpose, is again measured with the same care and attention to minutiae as were bestowed on the measurement of the original Base Line. The Line measured is called the Base of Verification. Its object is by comparing the result of the computation with that of the measurement, to check the error of the Triangulation.

After the measurement of the Base Line at the origin of the Survey, the next step is the selection of the Stations for the Triangulation, or the division of the country to be surveyed into a series of large triangles, the angles of which are placed at Stations clearly visible from each other.

Selection of Stations.

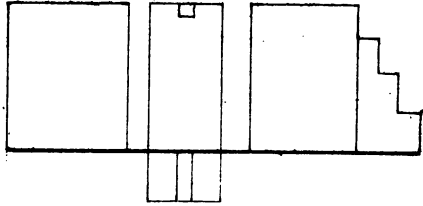
The most conspicuous Stations are selected as Trigonometrical points and are chosen with reference to their relative positions—as the nearer these triangles approach to being equilateral, the less will be the error in the resulting sides consequent on any slight inaccuracy in the observed angles ; but this being difficult in practice, the rule is to admit no angle under 30° or above 90° . The main series of the Triangulation should consist of triangles as large as the natural features of the country will admit of—from 15 to 20 miles is a very convenient distance for Principal Stations in hilly countries, because objects can be seen at such distances without much difficulty in ordinary conditions of the atmosphere. If, as is frequently the case, the highest peaks are inaccessible, it will be necessary to adopt a lower point, although the greatest effort should of course be made to reach the summit when practicable ; in the case of a lower point being used care must be taken that the view is clear in the direction of the Stations in advance.

It is the practice to mark all spots where angles are taken whether they be Principal or Secondary Stations. The mark is a dot with a concentric circle cut on stone by means of a pointed chisel. If the mark can be engraved on the rock *in situ*, so much the better, otherwise a large stone, properly marked, ought to be buried in the ground ; over this a small platform is raised, on the summit of which another markstone is inserted, and fixed truly vertical over the lower one. The distance between the two marks should be recorded, but all measurements and observations are usually referred to the upper mark and are stated to be so.

Sometimes, on account of intervening obstacles, it is necessary to raise the platform to a considerable height, in which case several markstones are always inserted and their relative heights recorded.

For Principal Stations it is necessary to make that part of the platform, on which the instrument stands, separate and dis-

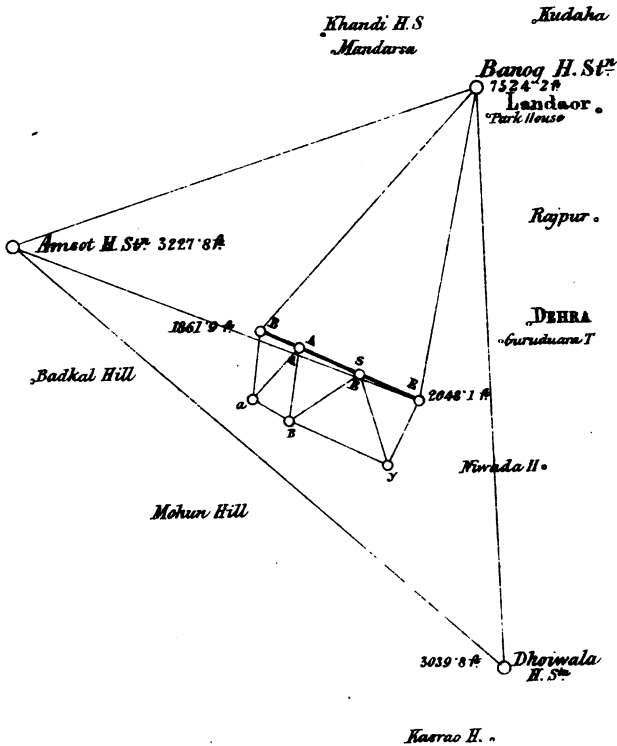
tinct from that on which the observer and his assistants walk. The instrument is then said to be "duly isolated." Unless this precaution is taken, good angles cannot be expected as the instrument will be liable to irregular disturbance,



according to the position of the observer. The annular space between the observer's stage, and the central pier, should be filled up with gravel, or sand, otherwise screws and other parts of the apparatus may be lost. Besides the upper markstone it is usual to imbed on the pier three picked flat heavy stones for the tripod of the instrument to stand upon, these are called "feet stones." It is not usual, if it can be avoided, to make isolated platforms at Secondary Stations in localities where the ground is very unsteady, such as deep black cotton soil, it may be practicable to steady a Theodolite by using pickets 4 feet long, and driving them into the ground, for the stand of the Theodolite to rest upon, as described before at page 328. The pickets isolate themselves for at least one foot in driving, but this precaution can only be taken at a new Station, otherwise the mark would be disturbed.

As soon as all the observations have been taken at, and to, any Station, and it is no longer required for the purposes of the Trigonometrical Survey, it should have the pole and brush and pile of stones erected on it, as shewn at page 396, in order that it may be visible to the detail Surveyors. This precaution has the further advantage of protecting the markstones.

As the measured bases average from $5\frac{1}{2}$ to $7\frac{1}{2}$ miles, it will perhaps be useful to point out a convenient method of deriving by means of symmetrical triangles, sides of continuation of 15 to 20 miles in length from a comparatively small measured distance.



On reference to the annexed sketch, which is extracted from Col. Everest's plan of the Great Arc Series, it will be seen that the first triangle formed upon the measured base is nearly isosceles. If it had been perfectly isosceles with an angle of 30° at the vertex, then the two longest sides which can be derived simultaneously from a given distance would have been obtained: a result, which it will be perceived has been approximated to as nearly perhaps as the configuration of the country would have allowed, by the first triangle in the sketch.

Again, upon one of the long distances (east end Base to Banog) furnished by this triangle, triangle No. 2 is formed, the

base whereof ($13\frac{1}{4}$ miles in length) being opposite to the smallest angle, the other two sides respectively measure $18\frac{1}{4}$ and $20\frac{3}{4}$ miles. The longer of these distances (Amsot to Banog) the extremities of which being defined by high peaks, forms therefore a convenient base of continuation, for the extension of the Triangulation to the north and south as may be required.

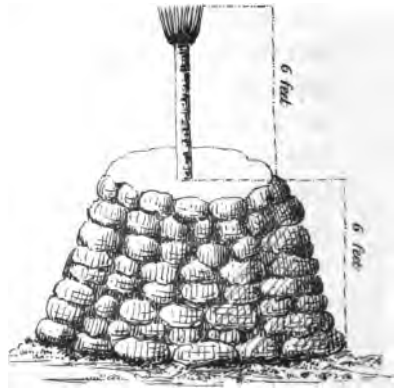
The signals used for Trigonometrical Surveys in former times were—

Signals.

- 1st. Flags.
- 2nd. The Pole and Brush.
- 3rd. Blue Lights.
- 4th. Vase Lights.

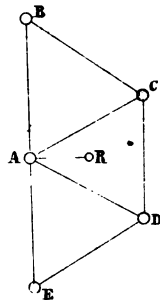
Flags are unfavorable for distant Stations because the Staff cannot be seen, and the cloth is of course blown aside by the wind. The flags for Principal Stations used to be 12 feet square, one-half being blue and the other half white. Those for Secondary Stations are 6 feet square. The blue and white cloth should be placed one above the other, and not side by side. The pole and brush is erected thus. A long straight pole is selected, upon the top of which a brush of twigs is fastened; the pole is placed truly perpendicular over the Station mark, and a pile of stones raised round it, by means of which it is securely fixed. The diagram in the margin will give a clear idea of this signal, which is a very economical and useful opaque object for day observation. The pile of stones may be 5 or 6 feet high and the pole about as much longer.

Blue lights are very powerful and can be seen at distances of 50 or 60 miles. They are also



useful at nearer distances in hazy weather, when other signals are not visible; if not carefully sheltered from the wind by grass screens, the flame is liable to be blown aside. On this account it was the practice of Col. Everest, the late Surveyor General of India, to burn them behind an iron screen, in which an aperture had been cut 3 or $3\frac{1}{2}$ inches in diameter, and the centre thereof was duly plumbed over the Station mark. The blue light fastened on the end of a stick, was held carefully behind this hole, and no part of the flame could therefore be visible to the distant observer, except through the circular aperture, which having been adjusted over the Station, ensured accuracy.

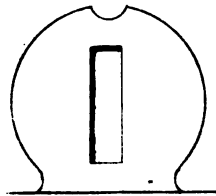
Blue lights being expensive articles cannot be kept constantly burning, but are fired at regular intervals of time by an assistant. They are usually cut in lengths to burn about 4 minutes and are fired at 5 minute intervals, which enables the observer to read off the observation, and also to observe and read off the referring lamp. After every second or third blue light a longer interval of say 10 minutes or $\frac{1}{4}$ of an hour is allowed to elapse, in order to allow time for changing zero of the instrument, which will be described hereafter. To prevent confusion blue light angles are always taken with a referring lamp as shown in the diagram. Supposing for example the observer is at A and has to observe B, C, D, E, by means of blue lights, a convenient mark is selected at say R about 2 to 3 miles distant, and a lamp is constantly burned there, during the time of night observations, and during the day a flag staff, or light vane, is used. Suppose the blue lights are first fired at Station B, then after every intersection of Station B, the readings are noted, the Telescope is then turned to R and the readings thereof noted, whence the angle BAR is deduced by direct observation. Similarly at another



period of the same night, or the next night, the $\angle CAR$ is taken, and so forth, whereby the $\angle BAC$ may be deduced by the equation $BAR - CAR = BAC$. The angle CAD by the equation $CAR + DAR = CAD$ and so on. It is a rule, that if any portion of the series of angles is taken with a referring lamp, the whole are to be taken in the same manner, otherwise confusion would arise; also in taking the series of observations required for determining CAR , the readings of R must always be the same within a minute or two, with the view of measuring the angle BAC , on entire arcs of the limb agreeably to the system practised in the Great Trigonometrical Survey, explained in the subsequent part of this Chapter.

Vase lights were invented by Col. Everest nearly 30 years ago and completely altered the operations of the Great Trigonometrical Survey in India, which had previously to be carried on, in the unhealthy season of the rains, in order that the opaque signals, such as flags, might be clearly seen. By enabling observations to be rapidly taken at night, the progress of the work was also much accelerated. ●

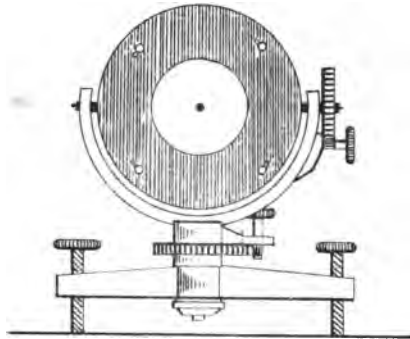
The vase light consists of a common earthen dish about 10 inches in diameter, (more or less according to distance,) and filled with cotton seeds and common oil. This is placed upon the station, and to prevent the flame being blown aside, a large earthen pot in the side of which an aperture has been cut is inverted over the dish, as shewn in the diagram, an aperture is also cut in the top to allow the smoke to escape. Further protection is necessary from high wind, by means of grass screens and blankets, leaving merely the requisite opening in the direction of the ob-



server. The materials for this light are procurable in nearly every village.

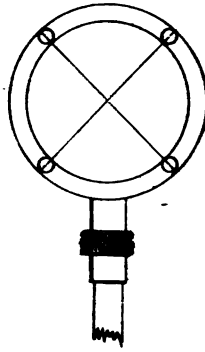
Trigonometrical operations in Southern India were entirely conducted by means of the foregoing signals, more especially the vase light for Principal Stations, and the pole and brush for Secondary Points. During the last 17 years however, signals of modern invention have been employed on account of their superior economy, convenience and power. These consist of Heliotropes, Argand reverberatory lamps, and Drummond lights. The latter surpass all previous contrivances, a ball of lime, about a quarter of an inch in diameter, placed in the focus of a parabolic reflector, and raised to an intense heat by a stream of oxygen gas directed through a flame of alcohol, produces a light eighty times as intense as that given by an Argand burner, and is visible even in hazy weather at a distance of 60 and 80 miles.

The Heliotrope consists of a circular piece of flat plate glass mirror, about 9 inches in diameter, with a small unsilvered aperture in the centre about 0.1 of an inch in diameter as represented in the figure. This mirror is mounted on a frame which stands on a tripod for the sake of steadiness.



The frame admits of the looking-glass being turned on a horizontal axis as well as on a vertical axis. These two motions in altitude and azimuth are regulated by means of rack work and they permit the reflection of the sun's rays to be turned in any required direction. In order that it may be directed truly to the observer, a ring with cross-wires, is placed at a distance of about 3 feet; the signal man then looks through the unsilvered aperture in the centre of the

Heliotrope and moves the cross-wires until they intersect the distant station. Thus the centre of the Heliotrope, the centre of the wires, and the observer's station form one right line. Now, if by means of the rack work the mirror is moved in altitude and in azimuth until the sun's rays fall on the wires, it is evident that the light will proceed straight to the obser-

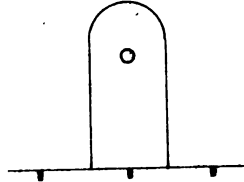


ver's Station; but the pencil of rays must be duly bisected by the wires, which intersection can be managed with ease and delicacy, by means of a little circle of white paper placed at the crossing of the wires, upon which paper the reflection of the little aperture in the centre of the mirror may be seen like a small dark speck. When the weather is hazy, the signal man will of course be unable to see the observer's station, in which case, unless a nearer mark has been given to guide him or a directing line has been drawn for him, he will be so far helpless. Under such circumstance, the observer ought to direct one or more Heliotropes towards the man and keep them playing until he has adjusted his apparatus. Similarly, if the man is careless and neglects to keep the sun's rays constantly shining in the true direction, the observer has only to flash a Heliotrope at him, to keep him alert.

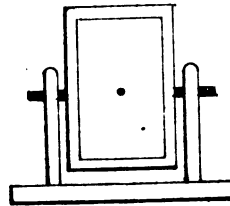
A Heliotrope of 9 inches, will answer for 90 or 100 miles; for nearer distances it is much too bright to be observed through a Telescope, and the light must be diminished in the following proportion. For distances of 2 or 3 miles (the usual distance of a referring mark) an aperture of 0.25 of an inch will answer, and for longer distances about 0.1 of an inch of aperture per mile of distance will suffice, viz. an inch for 10 miles, 2 inches for 20 miles, and so on, provided always

the apparatus is carefully adjusted and the man, who works it, is alert and skilful.

These apertures are cut in a board which stands upon 3 feet (as shewn in the figure) by means of which the centre of the aperture can be adjusted plumb over the Station mark. This board is called a Sight Vane, and stones are placed on the tail piece to prevent its being disturbed by the action of the wind. If this sight vane be used, the wires before described are unnecessary, because cross-hairs can be fixed in the vane, and will become a substitute for the wires. The Heliotrope is in this case placed 2 or 3 feet in rear of the Sight Vane, and moved laterally and vertically, until the eye applied to the centre unsilvered dot, views the observer's station and the cross-hairs in one line. The Heliotrope must be secured in this position, and the means of doing so will readily suggest themselves. It is needless to say that it must be quite firm.



A very good substitute for a regular Heliotrope has been frequently made out of a good looking-glass, with a flat surface. A small hole is drilled through the centre of the back board of the looking-glass and the silvering scraped off. This aperture should be truly central. The looking-glass is then swung in a frame of wood in such a way that the axis of motion shall pass through the unsilvered aperture. This frame is fixed upon a vertical axis which ought also to coincide with the unsilvered dot in the mirror. Finally, the vertical axis is planted on a board with 3 foot screws for adjustment. They have been fre-



quently used with success, on the subordinate series of the Great Trigonometrical Survey as well as in the Revenue Survey, and being powerful as well as economical instruments, they will be found very useful. By means of them and vane lights, work can be carried on with great rapidity, because the only limit to the times at which observations can be made will be from 9 o'clock A. M. to $2\frac{1}{2}$ or 3 o'clock P. M. But the Heliotrope is more particularly recommended for the purpose of taking vertical angles with certainty between the hours of $2\frac{1}{2}$ and $3\frac{1}{2}$ afternoon, which is the time of minimum refraction, because verticals taken at any other times are subject to great irregularities, whereby heights deduced from them are nearly worthless. Luminous objects are much more correctly, rapidly, and comfortably observed than opaque ones, which if distant, are always faint, and disappear when brought near the wire of the Telescope.

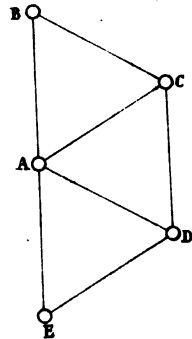
Method of
Observing.

In advancing the Field-work, it is necessary that the angles be read on the whole limb of the Theodolite, for thus the error of graduation is obviated. It is also to be borne in mind, that the real basis of all angular measurements is the graduation of the Theodolite. Suppose a 12-inch Theodolite is used, and the sides of a triangle are about 10 miles, the chord of the angles on the Theodolite will be little more or less than 6 inches, and the accuracy of the angle depends on the graduation defining this chord with great precision. The space on the Theodolite, in fact, represents in miniature the actual space in the Field, hence the necessity for *great care* when angular measurements are concerned. From this follows the necessity to change zero, and to take care that the Theodolite is an absolute fixture; the least shake in the ground ruins the angle. The instrument must be placed on firm ground, such as rock, or other methods adopted for isolating the instrument from the observer. On account of the want of firmness and immobility of the folding stands, for 7-inch and smaller sized Theodolites, they have now been discarded both from the Trigonometrical and Revenue Survey departments, and braced tripod head-stands

substituted as described in page 130. These also form a good stand for the plane table or drawing board, so that after the angular work is completed, the Surveyor can sketch in the ground. A good 7-inch Troughton and Simms' Theodolite mounted in this way, and always placed on firm ground, unshakable by the observer, will give excellent work for minor triangulation, provided proper signals are used.

All observations taken to elevated objects are subject to two great sources of errors, arising from dislevelment of the transit axis, and want of adjustment for the collimation. These causes of error are generally large in small instruments, and although capable of practical adjustment and rectification, still adjustments do not long remain, hence the system of observation should have the property of cancelling all such residual errors. This system is merely change of face, *i. e.*, observing alternately with the vertical face to the right and left, whereby the errors of collimation and dislevelment of transit axis are completely eliminated. Too much regard cannot be paid to this principle in all horizontal angles, whether to elevated or non-elevated objects, for as it is easily practised, so is the effect complete. No confidence can, in fact, be placed in observations on a single face, unless there is *evidence* of the perfect adjustment of the instrument and such evidence is never forthcoming.

The angles at a Station are taken thus, supposing the observer, at A, and the signals, at B, C, D and E, are all visible, the instrument is carefully levelled and adjusted and so fixed that some Station, B for instance, reads 0 or zero, then B is called the zero point. Suppose the Telescope to be brought up from the left hand of B and turned gently, so that B may enter the field of view and come near the centre wire, but not pass over it. Then clamp the instrument and complete the bisection of B by using the tangent screw of



slow motion. Read off all the micrometers or verniers, and let an assistant record the readings in a fair legible hand in the angle book. Look again into the Telescope and see that B remains bisected; if found correct, then carefully unclamp and move the Telescope gently towards C, taking care not to overshoot it; Clamp, bisect and read off as before, and so on for D and E. A complete round of observations at zero 0, taken by a continuous motion of the instrument from left to right, will thus be obtained. Now overshoot the Station E, and bring the Telescope back by a continuous motion from right to left, observing each Station in succession and recording the readings; this will give a second set at zero 0, which will suffice. It is the practice of the Trigonometrical Survey to make always one repetition at least, in order that mistakes may not creep in, and pass undiscovered.

Now turn the Telescope over 180° in altitude and round 180° in azimuth, so that if the face of the vertical circle were previously to the left hand, it will now be to the right hand of the observer, B will then read 180° , and this is called zero 180° F R, (face right) the former position being zero 0° F L, (face left.) Proceed as before and take two sets of observations, the motion of the instrument being in one set continuous from left to right, and in the other from right to left, as before.

Now if the instrument be supplied with an uneven number of micrometers, 3 for instance,* it is clear that at zero 0 the readings will be at 0° , 120° and 240° , while the readings at zero 180° , will be at 180° , 300° and 60° , whereby these two zeros give readings at every 60° of the limb. It is the practice on the Great Trigonometrical Survey to take observations at every 10° of the limb for the purpose of eliminating errors of graduation. This object is accomplished by shifting the body of the instrument, so that the zero station may successively read 0° , 10° , 20° , 30° , 40° and 50° , which, with the respective opposite

* The great or 24-inch Theodolites have 5 microscopes. The 18-inch instruments have 3 microscopes, and the 12, and 7 and 5-inch have 3 verniers.

faces, viz., 180° , 190° , 200° , 210° , 220° and 230° , gives every 10° of the limb as required.

When two observations of the same angle are made in the way described before on any part of the limb, they will occasionally exhibit a difference much greater than will be warranted by the power of the Theodolite used. When this happens, it is customary to take a third, a fourth, and sometimes even a fifth observation on the same zero, so that the mean result may be affected as little as possible by the discrepancy above adverted to.

Whatever however may be the number of observations made on any part of the limb, their arithmetical mean is computed and treated as an integral observation. For an angle therefore which has been observed on a given number of zeros, there will be the same number of integral observations deduced, the arithmetical mean whereof is the true value of the angle.

It is a fixed rule in the Great Trigonometrical Survey never to reject an observation, unless there be some obvious error in it, the circumstance of its differing, however widely from the mean, is not of itself a sufficient cause for its expunction.

The extent of operations on a Revenue Survey does not, however, call for this extreme precaution, and as the vernier of a 12-inch instrument is graduated to 10 seconds, and by estimation reads 5 seconds, no good purpose would be attained by multiplying observations to the above extent, and readings at every 30° are sufficient. Upon this principle the zeros to be adopted, are 0° and 180° , 30° and 210° , whereby, with 2 sets at each, there will be 8 sets, from which a good mean result may be derived, and a smaller number of observations for primary triangulation of the Revenue or detail Survey, would not be satisfactory.

It is clearly to be understood that the change of zero should be regular, that is to say, that the readings should be uniformly distributed at equal intervals round the limb, otherwise, the

probability of eliminating the errors of graduation will be diminished.

In the foregoing instructions the signals at all the Stations have been supposed to be simultaneously visible, which is frequently, but not always the case. It is generally so when lamps are used at night, but, when Heliotropes are employed, it is evident that an eastern Station will be seen with difficulty in the morning, whereas in the evening the Heliotrope will shine vividly, and *vice versa* in the case of a western Station, similarly there will be great changes in the appearance of flags as the position of the sun varies. Under these circumstances, the observations cannot always be taken in regular rounds in the simple manner before described. The best plan in this case is to use a referring mark, and connect each Station therewith at such times, as may be most convenient for observation.* This arrangement involves the necessity of frequently shifting the instrument so as to return to former zeros, and care must be taken that on each recurrence, the referring lamp be made to read nearly the same minutes and seconds as before. It is usual but not essential to make the referring lamp the zero Station. If, however, there be among any of the principal Stations to be observed, one peculiarly well situated, with every probability of being visible at all hours, it may conveniently be adopted and treated as a referring mark, whereby the extra labor of observing a supplemental point will be saved.

The observations are to be recorded in a book, the method of keeping which will be understood from the subjoined specimen. The headings of the different columns are so explicit, that no further explanation of them appears necessary. The written characters L and R in the column entitled "face and zero," mean face left and face right, alluding to the position of the vertical circle; and the figures 0° , 180° , &c., annexed to those characters, refer to the zeros.

* The method of deducing angles when a referring mark has been made use of, has already been explained at page 397.

SPECIMEN OF THE ANGLE BOOK.
Morning Angles taken at Durgapur Hill Station, 29th February, 1844.

Objects.	Face and Zero.	Micrometer Readings.				Angles.	Remarks.
		A	B	C	Means.		
Phuljori, Heliotrope,	..	237 37	36 15.5	37 15.4	237 36	57 36	7.83
Ghati, "	..	179 60	59 50.9	61 30.5	180 0	57 36	49.87
Ghati, "	..	179 60	59 50.6	61 30.8	180 0	57 36	49.80
Phuljori, "	..	237 37	36 10.1	37 12.0	237 36	57 36	47.87
Phuljori, "	..	57 36	36 28.6	37 41.2	57 36	57 36	45.27
Ghati, "	..	0 0	0 32.0	.1 2.3	0 0	57 36	35.37
Ghati, "	..	0 0	0 13.0	1 4.4	0 0	57 36	37.37
Phuljori, "	..	57 36	36 8.0	37 42.0	57 36	57 36	47.88
Phuljori, "	..	67 36	36 34.1	37 40.9	67 36	57 36	49.80
Phuljori, "	..	10 0	0 40.4	1 10.8	10 0	57 36	40.90
Ghati, "	..	10 0	0 43.5	1 14.4	10 0	57 36	44.23
Phuljori, "	..	67 36	36 14.1	37 41.7	67 36	57 36	50.10
<i>Afternoon Angles taken at Durgapur Hill Station, 29th February, 1844.</i>							
Phuljori, Heliotrope,	..	247 37	36 27.4	37 38.6	247 37	57 36	12.97
Ghati, "	..	189 61	59 57.7	61 50.4	190 0	57 36	58.73
Ghati, "	..	190 1	0 0.9	1 54.5	190 1	57 36	1.97
Phuljori, "	..	247 37	37 6.6	37 43.2	247 37	57 36	17.00
Phuljori, "	..	77 36	36 48.3	38 22.4	77 37	57 36	21.57
Ghati, "	..	20 0	0 45.6	2 3.6	20 1	57 36	19.80
Phuljori, "	..	77 36	36 54.8	38 25.8	77 37	57 36	25.27
Ghati, "	..	20 0	0 46.8	2 10.5	20 1	57 36	21.20
Phuljori, "	..	257 37	36 51.0	37 50.7	257 37	57 36	28.73
Ghati, "	..	200 1	0 19.5	2 8.0	200 1	57 36	18.73
Phuljori, "	..	200 1	0 31.5	2 12.7	200 1	57 36	22.47
Ghati, "	..	257 37	36 51.1	37 52.3	257 37	57 36	31.97

Night Light Angles taken at Durgapur Hill Station, 29th February, 1844.

Objects.	Face and Zero.	Micrometer Readings.						Remarks.
		A	B	C	Means.	Angles.		
Phuljori, Lamp,		87 36 36.9	36 38.3	38 8.0	87 37 7.73	57 36 3.56		
Ghati, "	1 30°	80 0 29.5	0 49.3	1 53.7	80 1 4.17			
Ghati, "		30 0 31.0	0 53.7	1 56.9	30 1 7.20			
Phuljori, "		87 36 35.3	36 40.3	38 9.2	87 37 8.27	57 36 1.07		
Ghati, "		210 1 7.7	0 2.5	1 49.5	210 0 59.90			
Phuljori, "		267 37 28.1	36 39.4	37 32.5	267 37 13.33	57 36 13.43		
Phuljori, "		267 37 30.0	36 40.7	37 33.5	267 37 14.73	57 36 8.83		
Ghati, "	R 210°	210 1 15.1	0 9.4	1 53.2	210 1 5.90			
Ghati, "		220 1 37.8	0 27.0	2 7.9	220 1 24.23			
Phuljori, "		277 37 49.0	37 11.1	37 57.1	277 37 39.07	57 36 14.84		
Phuljori, "		277 37 44.9	37 6.4	37 50.7	277 37 34.00	57 36 8.07		
Ghati, "	R 220°	220 1 41.1	0 25.3	2 11.4	220 1 25.93			
Ghati, "		220 1 41.0	0 25.2	2 9.8	220 1 25.83			
Phuljori, "		277 37 46.5	37 5.5	37 56.1	277 37 36.03	57 36 10.70		
Ghati, "		40 1 1.8	1 6.3	2 14.8	40 1 27.63			
Phuljori, "	L 40°	97 37 17	37 5.8	38 27.5	97 37 31.67	57 36 4.04		
Phuljori, "		97 36 55.7	37 5.2	38 27.9	97 37 29.60	57 36 1.13		
Ghati, "		40 0 52.2	1 5.0	2 28.2	40 1 28.47			
Ghati, "		50 0 13.5	0 23.2	1 52.1	50 0 51.60			
Phuljori, "	L 50°	107 36 30.5	36 18.0	38 5.5	107 36 58.00	57 36 6.40		
Phuljori, "		107 36 24.2	36 21.0	37 60.1	107 36 55.10	57 36 1.63		
Ghati, "		50 0 14.3	0 23.6	1 56.5	50 0 53.47			
Ghati, "		229 61 2.1	59 50.5	61 27.2	229 0 46.60			
Phuljori, "	R 230°	287 37 9.1	36 36.8	37 8.8	287 36 58.23	57 36 11.63		
Phuljori, "		287 37 12.6	36 42.0	37 9.4	287 37 1.33	57 36 16.70		
Ghati, "		229 61 4.3	59 48.0	61 21.6	229 0 44.63			

Synopsis of the foregoing observations, arranged under their respective Zeros.

∠ GHATI AND PHULJORI, 57° 36"

0°	180°	10°	190°	20°	200°	30°	210°	40°	220°	50°	230°
"	"	"	"	"	"	"	"	"	"	"	"
9-90	7-88	9-00	14-24	1-77	10-00	3-56	13-43	4-04	14-84	6-40	11-68
10-46	4-07	5-87	15-03	4-07	9-50	1-07	8-83	1-13	8-07 10-70	1-68	16-70
10-18	5-96	7-44	14-64	2-92	9-75	2-32	11-13	2-59	11-20	4-02	14-17

General Mean 57 36 8-03

DURGAPUR HILL STATION DESCRIBED.

Durgapur Hill Station is situated about a mile east of the village of the same name in the Jungul Mehal's District. It has the respectable village of Pandra about 4 miles S. W. There are two roads to the station from Durgapur village, the shortest or the one directly east is steep, while the other which commences from the north foot of the hill, is of gradual ascent and circuits. A platform points out the station of observation. It has another hill about 5 miles north called Budmah, which is also marked."

32 F

The angle book should on no account ever be suffered to fall in arrears. The original should be examined by two computers, and attested by their signatures, and the name of the observer should be recorded. The duplicate should be compared with the original by two persons and likewise attested by their signatures. It is a standing rule in order to exclude errors, that all computations and comparisons should be performed independently by two persons, and attested by their signatures, and unless such precautions have been observed, the results are considered untrustworthy as final work.

It is convenient to keep an Observatory Memorandum Book, for the purpose of registering all sorts of remarks, and it is usual to insert in this book the results of observations, as they are taken, in order that the observer may be able to see at a glance how the work is progressing.

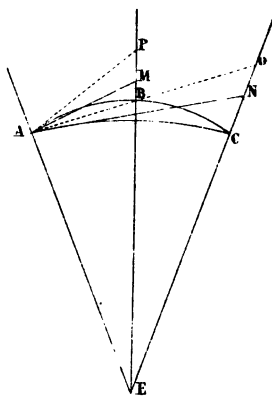
CHAPTER XVII.

ON THE COMPUTATION OF GEODETICAL TRIANGLES.

WITH respect to the angles thus observed, and the triangles formed from them, they are not, rigorously speaking, *plane*, but *spherical*, existing on the surface of a sphere, or rather, to speak correctly, of a spheroid. In small triangles, of six or seven miles in the sides, this consideration may be neglected as the difference is imperceptible; but in larger ones it must be taken into consideration.

“ It is evident that as every object used for pointing the telescope of a Theodolite has some certain elevation, not only above the soil, but above the level of the sea; and as, moreover, these elevations differ in every instance, a reduction to the horizon of all the measured angles would appear necessary. But in fact, by the construction of the Theodolite, which is nothing more than an altitude and azimuth instrument, this reduction is made in the very act of reading off the horizontal angles.

Let E be the centre of the earth; A, B, C , the places on its spherical surface to which the three stations, A, P, O , in a country are referred, by radii EA, EB, EC . If a Theodolite be stationed at A , the axis of its horizontal circle will point to E when truly adjusted, and its plane will be a tangent to the sphere at A , intersecting the radii EB, EC , at M and N , above the spherical surface. The telescope of the Theodolite,



it is true, is pointed in succession to P and O ; but the readings of its azimuth circle give,—*not* the angle PAO between the directions of the telescope, or between the objects P, O , as seen from A , but the azimuthal angle MAN , which is the measure of the angle A of the spherical triangle BAC .

The true way then of conceiving the subject of a Trigonometrical Survey, when the spherical form of the earth is taken into consideration, is to regard the network of triangles into which the country is divided, as the bases of an assemblage of pyramids converging to the centre of the earth. The Theodolite gives us the true measures of the angles included by the planes of those pyramids; and the surface of an imaginary sphere at the level of the sea, intersects them in an assemblage of spherical triangles, above whose angles, in the radii prolonged, the real stations of observation are raised by the superficial inequalities of mountain and valley.” *

Having shewn that the triangles described upon the surface of the earth are spherical triangles, we will now proceed to lay down the rules by which they may be computed.

One property of a spherical triangle is, that if its three angles were added together, their sum would be greater than π or

* *Herschel's Astronomy*

180°.* Calling therefore A, B, C , the angles of a spherical triangle, we shall have $A + B + C = \pi + e$.

The term e by which the sum of the angles exceeds a semi-circle or π , is called the spherical excess of the triangle.

On a little consideration it will be evident that the computation of the spherical excess of a triangle is a circumstance of great moment, for unless that term is known, the accuracy with which the angles have been observed, can never be ascertained, nor as it will afterwards appear, can the triangle itself be computed as a spherical triangle.

The rigorous formula as established by writers on spherical trigonometry, for the computation of the spherical excess is this:

$$\text{Tan } \frac{1}{2} e = \frac{\tan \frac{1}{2} b. \tan \frac{1}{2} c. \sin A}{1 + \tan \frac{1}{2} b. \tan \frac{1}{2} c. \cos A}$$

in which b and c represent the two spherical sides, the former being opposite to B and the latter to C .

Although this formula for the spherical excess possesses a neat and compact form, it is far from being susceptible of an easy arithmetical computation, particularly when it is applied to such triangles as those presented by a Trigonometrical Survey of an ordinary description. To adapt the formula therefore to this exigency, it will require to be evolved into a series. This done, and putting r for the mean radius of the earth, the value of e in seconds will stand as follows:

$$\begin{aligned} e'' &= \frac{bc \sin A \operatorname{cosec} 1''}{2 r^2} \\ &+ \frac{b^3 c \sin A \operatorname{cosec} 1''}{24 r^4} \\ &+ \frac{bc^3 \sin A \operatorname{cosec} 1''}{24 r^4} \\ &+ \frac{b^2 \cdot c^2 \sin 2A \operatorname{cosec} 1''}{16 r^4} \\ &\dots \dots \dots \end{aligned}$$

* Ramsden's large Theodolite, three feet in diameter, was the first instrument by which this excess, called the spherical excess, was observed. It is always a minute quantity, seldom exceeding 4" to 5" in the triangles used in geodetical operations.

In this series the first term is only effective, and the other terms being very minute may be thrown out of consideration. Supposing b and c to be given in terms of some linear unit, it is evident that $\frac{bc \sin A}{2}$ will represent the area of the given spherical triangle computed as a plane one, such an area therefore multiplied by the constant ratio $\frac{\text{cosec } 1''}{r^2}$ will give the spherical excess in seconds.

In practice, however, the distances b and c are rarely known, the given elements being generally one side a , and the three angles A, B , and C . If therefore the area of the triangle is required in terms of these elements, it will be equivalent to $\frac{a^2 \sin B \sin C}{2 \sin A}$

The computation of the spherical excess of a triangle does not demand, that its angles and sides should be known to any degree of nicety. It will be sufficient if the former are taken at their observed values to the nearest second: altering these values when required by equal amounts to make their sum amount to π . Either from these data, or from the sides derived therefrom, the spherical excess may be deduced, which will be true to within the limits of accuracy usually required in practice.

As an example of the computation of the spherical excess, take the 23rd triangle from p. 261, of Colonel (then Capt.) Everest's account of the measurement of the Great Indian Arc, published in 1830, assuming the mean Radius of the Earth to be 20888153.2 feet, which is the numerical value of r , in the formula before given.

<i>Yemsha to Shevalingapah a = 136352.16 feet</i> <i>Log. 5.1346620.</i>						
Stations.	Characteristic marks.	Observed Angles.		Seconds of corrected Angles.	Sines of corrected Angles.	Computed sides.
Yemsha,	C	°	'	"	"	
Shevalingapah,	B	70	56	45.966	41	9.9755256
Yaenagapally,	A	59	4	9.423	4	9.9333739
		49	59	20.567	15	9.8841744
Yaenagapally to Yemsha....		$b =$		{ Feet,		152708
				{ Log.,		5.1838615
Ditto to Shevalingapah....		$c =$		{ Feet,		168273
				{ Log.,		5.2260132

SPHERICAL EXCESS COMPUTED.

First Process.

Log. b	5.1838615
Log. c	5.2260132
Log. $\sin A$	1.8841744
A. C. Log. 2	1.6989700*
Log. cosec $1'$	5.3144251
A. C. Log. r	$\left. \begin{array}{l} \bar{8}.6800999 \\ \bar{8}.6800999 \end{array} \right\}$
Log. e	0.6676440
	"
	$e = 4.652$

Second Process.

Log. a	$\left. \begin{array}{l} 5.1346620 \\ 5.1346620 \end{array} \right\}$
Log. $\sin B$	1.9333739
Log. $\sin C$	1.9755256
Log. cosec A ..	0.1158256
A. C. Log. 2	1.6989700*
Log. cosec $1'$..	5.3144251
A. C. Log. r	$\left. \begin{array}{l} \bar{8}.6800999 \\ \bar{8}.6800999 \end{array} \right\}$
Log. e	0.6676440
	"
	$e = 4.652$

* It greatly facilitates computation by combining these four Logarithms into one sum, and treating it as a constant Log.

Now let A' be the observed value of A , B' that of B , and C' that of C ; it is evident that $A' + B' + C'$ will never be equal to $\pi + e$ but will either be in excess or in defect of this amount.

This last circumstance may be expressed algebraically in the following manner $A' + B' + C' = \pi + e \pm \epsilon$ in which $\pi + e$ standing for the true sum of the angles, ϵ will be the error of observation.

In the triangle given above, the sum of the three angles
 $= \pi + 15.956$ and $e = 4.652$. Therefore $\epsilon = 11.304$.

It is clear that nothing certain can be advanced as to the origin of this error. It may be that the signals were not properly centered, or that the graduation and the adjustments of the instrument were imperfectly executed; or lastly, that there was a peculiarity or a defect in the eye of the observer. All these circumstances may have operated separately or in combination, to produce the discrepancy under consideration.

Supposing, however, that the three angles of the triangle have been taken with the same instrument, and with the same care, and by the same observer, it is extremely probable that each is liable to an equal amount of error. If this is admitted, it will follow that the best way of expunging ϵ , is by apportioning it equally amongst the three observed angles.

If the angles of the triangle before given are corrected by this process, they will stand as follows:

Stations.	Observed Angles.	Apportionment of Error.	Corrected Angles.
Yemsha,	70 56 45.966	-3.768	70 56 42.198
Shevalingapah,	59 4 9.423	-3.768	59 4 5.655
Yaenagapally,	49 59 20.567	-3.768	49 59 16.799
	180 0 15.956	11.304	180 0 4.652

The angles given in the last column, are called spherical angles. Their sum amounts (as it ought to do) to $\pi + e$. After the observed angles have been reduced to their spherical values, the computation of the geodetical triangle may be taken in hand.

Of the different deductive processes established by different writers for the accomplishment of this object, that laid down by LeGendre, possesses superior advantages on the score of its simplicity, expedition and accuracy. It is based on the assumption that the sides of a geodetical triangle which may be presented for computation, are very small in comparison with the radius of the earth; and it has been discovered by actual calculation, that a triangle whose sides do not exceed 450 miles, may be deduced by LeGendre's Theorem, without producing an error of one foot in the result.

This Theorem for the computation of a geodetical triangle may be stated as follows:—From each of the spherical angles of the triangle, deduced as directed in the former part of this Chapter, deduct one-third of the spherical excess. With the angles so diminished, compute the sides of the triangle by the rules of plane trigonometry, these sides (such is the result of LeGendre's investigation) will be equivalent in length, to the spherical sides of the given geodetical triangle. It may be added that when the spherical angles of a geodetical triangle are diminished by one-third of the spherical excess, they are called angles for computation, and that their sum must obviously amount to 180° .

In the Great Trigonometrical Survey of India, LeGendre's Theorem is made use of in the computation of the principal triangulation. As an example of which, let us take the triangle before given.

<i>Yemsha to Shevalingapah = 136352·16 feet,</i> <i>Log. 5·1346620.</i>				
Stations.	Spherical Angles.	Angles for Com- putation.	Sines.	Deduced sides.
Yemsha,	° / "	° / "	9·9755253	
Shevalingapah,	70 56 42·198	70 56 40·647	9·9333740	
Yaenagapally,	59 4 5·655	59 4 4·104	9·8841748	
	49 59 16·799	49 59 15·249		
Yaenagapally to Yemsha,			{ Feet,	152707·77
			{ Log.,	5·1838612
Ditto, to Shevalingapah,			{ Feet,	168272·23
			{ Log.,	5·2260125

COMPUTATION OF THE SIDES EXHIBITED.

First Side.

Yemsha to Shevalingapah,	Log.	5·1346620
∠ Yaenagapally,	cosec. or A. C. of sin.	0·1158252
∠ Shevalingapah,	sin.	9·9333740
		5·1838612
Yaenagapally to Yemsha,	{ Log.	5·1838612
	{ Feet,	152707·77
	{ Miles,	28·922

• *Second Side.*

Yemsha to Shevalingapah,	Log.	5·1346620
∠ Yaenagapally,	cosec. or A. C. of sin.	0·1158252
∠ Yemsha,	sin.	9·9755253
		5·2260125
Yaenagapally to Shevalingapah,	{ Log.	5·2260125
	{ Feet,	168272·23
	{ Miles,	31·870

The process of computation described in the foregoing pages is applicable to the principal triangulation of a series. In the

deduction of the Secondary Triangles however, such for instance as those for a Topographical Survey, all this attention to minutiae is never required; it being sufficient to consider these as plane triangles and compute them accordingly.

There is only one circumstance connected with the deduction of Secondary Triangles, which stands in need of some explanation at this place. In some Secondary Triangles, only two angles are observed, and in others all three. In the former case the two angles are added together, and the sum is deducted from π , the resulting difference is the third, or the supplemental angle. In the latter case the sum of the three angles is compared with π , and if any difference exists between the two amounts, it is apportioned equally amongst the three angles, employing the angles so corrected in the computation of the triangle.

The following examples extracted from the Report of the Great Trigonometrical Survey, will illustrate these methods of computation.

<i>Pirer to Paniari = 15441·8 feet, Log. 4·1886970.</i>					
Stations.	Observed Angles.	Apportionment of Error.	Angles for Computation.	Sines.	Deduced sides.
Pirer,	° ' " 53 26 57·5	+ 1·4	° ' " 53 26 59	9·9048965	
Paniari,	70 9 44·0	+ 1·5	70 9 45	9·9734322	
Mirpur, ..	56 23 14·2	+ 1·4	56 23 16	9·9205424	
	179 59 55·7	+ 4·3	180 0 0	.....
Mirpur to Pirer,				{ Feet,	17441·6
				{ Log.,	4·2415868
Ditto to Paniari,				{ Feet,	14896·4
				{ Log.,	4·1780511

<i>Paniari to Mirpur = 14895.4 feet, Log. 4.1730511.</i>					
Stations.	Observed Angles.	Apportion- ment of Error.	Angles for Computation.	Sines.	Deducted. sides.
Paniari, ..	° ' "	.....	° ' "	9-9984390	
Mirpur, ..	22 29 38	.....	22 29 38	9-5827278	
Tajpur, Vil- lage Tree Flag, }	Supplemen- tal Angle, }	.....	62 39 4	9-9485233	
	.....	.....	180 0 0	.....
Tajpur to Paniari,				{ Feet,	6416
				{ Log.,	3.8072556
Ditto to Mirpur,				{ Feet,	16710
				{ Log.,	4.2229668

CHAPTER XVIII.

ON THE COMPUTATION OF LATITUDES, LONGITUDES AND AZIMUTHS OF TRIGONOMETRICAL STATIONS.

LET A and B be two Trigonometrical Stations. The latitude and longitude of A , together with the distance of A to B at the sea level, and the azimuth of the line as appears to an observer at A , being given, it is required to deduce the latitude and longitude of B , and the azimuth of the same line BA as appears to an observer at B .

The symbols which are usually made use of, to represent the elements given, as well as those required, are as follows :

Elements given.

- λ Latitude of A
- L Longitude of ditto
- A Azimuth of B from A^*
- C Distance from A to B .

Elements sought.

- λ' Latitude of B
- L' Longitude of ditto
- B Azimuth of A from B .

Of the foregoing seven symbols, two only, namely, A and B , which stand for azimuths, require some explanation. In the Revenue Survey the origin of the azimuthal arc is placed in north, whence it proceeds by east to south, and thence again it returns by west to north. This is the common mode of reckoning the azimuth.

* The method of deriving the first or fundamental azimuth at the origin of the triangulation, will be found in Part V.

In the formulæ which will be given hereafter, the azimuthal arc will be taken to commence from south, and to proceed by west and north, round the whole circle of the horizon, as observed in the Great Trigonometrical Survey. According to this view, the azimuth of west will be 90° , that of north 180° , and lastly, that of east 270° .

It is necessary to mention at this place that there are two solutions of the problem under consideration, the spherical and the spheroidal. In the former the earth is supposed to be a sphere, in the latter it is taken as a spheroid. In this work we will adopt the spheroidal solution, in the first place, because it is more consonant to truth than the other, and secondly, because the process of computation it gives rise to, has been arranged by Col. G. Everest, late Surveyor General of India, into a form which is susceptible of easy and convenient application to survey operations.

In the computation of the Great Trigonometrical Survey of India, the dimensions of the earth supposed to be a spheroid are taken at the following values:

Axis Major $a = 20922931.8$ feet.

Ditto Minor $b = 20853374.6$ „

These elements are derived from a comparison of the Doda-gontah arc, comprised between Punnae and Kalianpur, measured prior to the year 1826, with the French arc beginning at Greenwich and ending at Formentera.

On a slight consideration it will be evident that if the differences $(\lambda' - \lambda)$, $(L' - L)$, $(B - \pi + A)$ could be computed by any process, λ' , L' and B could be easily deduced therefrom.

For instance supposing $\lambda' - \lambda = \Delta\lambda$, $L' - L = \Delta L$, and $B - (\pi + A) = \Delta A$, we shall have $\lambda' = \lambda + \Delta\lambda$; $L' = L + \Delta L$; and $B = (\pi + A) + \Delta A$.

The reason why these differential quantities $\Delta\lambda$, ΔL , ΔA , are computed in preference to λ' , L' and B , is that the former are susceptible of easier and more accurate deduction than the latter.

On reference to pp. 161 and 169, of Col. Everest's account of the Indian arc published in 1847, it will be seen that the values of $\Delta\lambda$, ΔL , and ΔA come out in infinite series. These series are rapidly convergent: Col. Everest uses only the first four terms and omits the others on account of their minuteness. For the purposes of this work, however, the first and second terms are all which will be required, the third and the fourth terms which are retained by Col. Everest being too minute to merit attention at this place.

Limited to the 2nd term, the formulæ for the computation of latitudes, longitudes and azimuths as arranged by Col. Everest, are as follows:

<i>For Latitude.</i>	<i>For Longitude.</i>	<i>For Azimuth.</i>
$\delta_1\lambda = P. \cos A. c$	$\delta_1L = \delta_1\lambda. Q. \sec\lambda. \tan A$	$\delta_1A = \delta_1L. \sin\lambda.$
$\delta_2\lambda = \delta_1A. R. \sin A. c$	$\delta_2L = \delta_2\lambda. S. \cot A$	$\delta_2A = \delta_2L. T.$
	<i>in which</i>	
$\delta_1\lambda + \delta_2\lambda = \Delta A$	$\delta_1L + \delta_2L = \Delta L.$	$\delta_1A + \delta_2A = \Delta A$

The terms P, Q, R, S, T, \dots which occur in these formulæ are composed of the numerical values of a and b given before, and of certain functions of the given latitude λ . Most of these terms are of tedious deduction, on which account it becomes necessary that they should be computed once for all, and registered under a Tabular Form, so as to be ready for use when required.

Accordingly in the Great Trigonometrical Survey of India, we have the Table of P, Q, R, \dots computed for every 10' of latitude between the parallels of 8° and 35° :— and we will give at the end of this Chapter an extract from this table, which will facilitate computations by Col. Everest's formulæ.

The arrangement of this table is so simple that it hardly requires any explanation. Enter the table with the given latitude λ of station A . If λ is exactly found in the table, take out P, Q, R, \dots just as they stand in a line therewith. This is a very simple operation, but the exact agreement which we have supposed to exist between the given and the tabular latitude, seldom takes place in practice. In most instances the given

latitude will lie between two tabular latitudes. In such cases take out P, Q, R, \dots appertaining to the next less tabular latitude and correct them in this wise. Take the difference between the given and the tabular latitude next less, and convert it to the denomination of a minute. The term so obtained being multiplied successively by the tabular differences for P, Q, R, S and T , and divided by 10, will furnish the required corrections, which will be negative in the case of P, R and T and positive in that of Q and S .

P, Q, R, S, T being computed, other terms of the formulæ, such for instance as $\cos. A, \tan. A, \sec. \lambda \sin. \lambda \dots$ may be taken out from a common table of logarithms.

When the terms $\delta_1\lambda, \delta_1L, \dots$ are computed, they will be in seconds and decimals thereof.

The signs of these terms dependant upon the magnitude of the given azimuth A , may be easily taken out from the following table.

Terms of the Formulæ.	Magnitude of the given Azimuth A .			
	1st Quadrant.	2nd.	3rd.	4th.
$\delta_1\lambda$	—	+	+	—
δ_1L	—	—	+	+
δ_1A	—	—	+	+
$\delta_2\lambda$	—	—	—	—
δ_2L	+	—	+	—
δ_2A	+	—	+	—

After proper signs have been prefixed to $\delta_1\lambda, \delta_1L$:—take the sums of $\delta_1\lambda$ and $\delta_2\lambda$:—of δ_1L and δ_2L :—and of δ_1A

and $\delta_2 A$. The three sums so obtained will be the values, the first of $\Delta\lambda$, the second of ΔL , and the last of ΔA .

Now $\Delta\lambda$ being applied to λ , ΔL to L , and ΔA to $(\pi + A)$ the resulting elements will be λ' , and L' and A' .

By way of illustrating the computation of the latitudes, longitudes and azimuths of Trigonometrical Stations we sub-join the following example.

Shevalingapah deduced from Yemshaw.

Station A Yemshaw.		Station B Shevalingapah.	
$\lambda=18^\circ 51'31''00$		$A =73^\circ 1'52''11$	
$L=78 1 0.79$		$\text{Log. } c= 5.1346620$	
P.	3.9962429		
Cos A	1.4651625		
c	5.1346620		
$\delta_1 \lambda$	2.5960674	..... - 394.52 = - 0 6 34.52	" " "
Q	1.9974090		
Sec λ	0.0239624		
Tan A	0.5155059		
$\delta_1 L$	3.1329447	..... - 1358.14 = - 0 22 38.14	" " "
Sin λ	1.5095169		
$\delta_1 A$	2.6424616	..... - 439.00 = - 0 7 19.00	" " "
R	3.38079		
Sin A	1.98067		
c	5.13466		
$\delta_2 \lambda$	0.13858	..... - 1.38	"
S	0.32241		
Cot A	1.48449		
$\delta_2 L$	1.94548	... + 0.88	"
T	0.23472		
$\delta_2 A$	0.18020	..... + 1.51	"

	°	'	"	
$\delta_1 \lambda$	=	—	0 6 34.52	
$\delta_2 \lambda$	=	—	1.38	
$\Delta \lambda$	=	—	0 6 35.90	
λ	=	—	18 51 31.00	
<hr style="border: 1px solid black;"/>				
λ'	=	—	18 44 55.10	Deduced Latitude of Shevalingapah.
<hr style="border: 1px solid black;"/>				
$\delta_1 L$	=	—	0 22 38.14	
$\delta_2 L$	=	+	0.88	
ΔL	=	—	0 22 37.26	
L	=	—	78 1 0.79	
<hr style="border: 1px solid black;"/>				
L'	=	—	77 38 23.53	Deduced Longitude of Shevalingapah.
<hr style="border: 1px solid black;"/>				
$\delta_1 A$	=	—	0 7 19.00	
$\delta_2 A$	=	+	1.51	
ΔA	=	—	0 7 17.49	
$\pi + A$	=	—	253 1 52.11	
<hr style="border: 1px solid black;"/>				
B	=	—	252 54 34.62	Deduced Azimuth of Yemshaw from Shevalingapah.
<hr style="border: 1px solid black;"/>				

When a point is determined by a triangle, it ought to have two deductions of latitude, longitude and azimuth derived from the stations defining the base of the triangle. For instance, referring to triangle at page 418, Yeanagopali may be computed from Yemshaw, as well as from Shevalingapah. In the Great Trigonometrical Survey, it is the invariable practice to go through the two deductions and compare the results, which when the two computations are correctly executed, will be identical.

Table exhibiting the Logarithmic values of P, Q, R, S and T, between the parallels of 18° and 35° of Latitude.

λ	P	Diff.	Q	Diff.	R	Diff.	S	Diff.	T	Diff.
18° 0'	3-9962818		1-9973831		8-38083		0-32021		0-25077	
10	2743	-75	3881	+50	82	-1	062	+41	4757	-320
20	2670	73	3929	48	81	1	104	42	4440	317
30	2593	77	3981	52	80	1	147	43	4128	312
40	2518	75	4031	50	80	0	190	43	3821	307
50	2441	77	4082	51	79	1	234	44	3518	303
		76	4133	51	79	1	278	43	3218	300
19 0'	3-9962365		1-9974133		8-38078		0-32277		0-23218	
10	2287	78	4185	52	77	1	322	45	2922	296
20	2209	78	4237	52	77	0	366	44	2629	293
30	2128	81	4291	54	76	1	411	45	2341	288
40	2049	79	4344	53	75	1	457	46	2057	284
50	1969	80	4397	53	74	1	503	46	1776	281
		81	4451	54	74	1	549	46	1499	277
20 0'	3-9961888		1-9974451		8-38073		0-32549		0-21499	
10	1807	81	4505	54	73	0	596	47	1224	275
20	1725	82	4560	55	72	1	643	47	0954	270
30	1645	80	4613	53	71	1	690	47	0688	266
40	1561	84	4669	56	70	1	738	48	0424	264
50	1477	84	4725	56	69	1	787	49	0164	260
		84	4781	56	68	1	836	49	0164	258
21 0'	3-9961393		1-9974781		8-38068		0-32836		0-19906	
10	1309	84	4837	56	68	0	885	49	9653	253
20	1224	85	4894	57	67	1	935	50	9402	251
30	1138	86	4951	57	66	1	985	50	9155	247
40	1053	85	5008	57	65	1	1035	50	8911	244
50	0964	89	5067	59	64	1	1086	51	8668	243
		84	5123	56	64	1	1137	52	8426	237
22 0'	3-9960880		1-9975123		8-38063		0-33138		0-18431	
10	0790	90	5183	60	62	1	1190	52	8195	236
20	0703	87	5241	58	62	0	1242	52	7963	232
30	0613	90	5301	60	61	1	1294	52	7732	231
40	0523	90	5361	60	60	1	1348	54	7506	226
50	0435	88	5420	59	59	1	1401	53	7282	224
		91	5480	60	58	1	1455	54	7061	221
23 0'	3-9960344		1-9975480		8-38058		0-33455		0-17061	
10	0253	91	5541	61	57	1	1510	55	6842	219
20	0162	91	5602	61	56	1	1565	55	6626	216
30	0070	92	5663	61	55	1	1620	55	6412	214
40	3-9959977	93	5725	62	54	1	1676	56	6202	210
50	9885	92	5786	61	53	1	1732	56	5994	208
		94	5849	63	52	1	1788	56	5791	207
24 0'	3-9959791		1-9975849		8-38052		0-33788		0-15787	
10	9698	93	5911	62	51	1	1846	58	5585	202
20	9603	95	5974	63	51	0	1903	57	5384	201
30	9507	96	6038	64	50	1	1961	58	5186	198
40	9411	96	6103	65	49	1	2020	59	4990	196
50	9317	94	6165	62	48	1	2078	58	4796	194
		96	6229	64	47	1	2137	60	4605	191
25 0'	3-9959221		1-9976229		8-38047		0-34138		0-14605	
10	9125	96	6293	64	46	1	2197	59	4416	189
20	9026	99	6359	66	45	1	2258	61	4230	186
30	8929	97	6423	64	44	1	2318	60	4045	185
40	8831	98	6489	66	43	1	2380	62	3863	182
50	8734	97	6554	65	42	1	2441	61	3683	180
		98	6619	65	41	1	2503	62	3505	178
26 0'	3-9958636		1-9976619		8-38041		0-34503		0-13505	
10	8534	102	6687	68	40	1	2566	63	3330	175
20	8434	100	6754	67	39	1	2629	63	3156	174
30	8333	101	6821	67	38	1	2692	63	2985	171
40	8234	99	6887	66	37	1	2756	64	2815	170
50	8132	102	6955	68	36	1	2820	64	2649	166
		102	7023	68	35	1	2885	65	2487	167

Table exhibiting the Logarithmic values of P, Q, R, S and T, between the parallels of 18° and 35° of Latitude.—(Continued.)

λ	P	Diff.	Q	Diff.	R	Diff.	S	Diff.	T	Diff.
27° 0'	3-9958030	-101	1-9977023	+67	5-38035	-1	0-34885	+65	0-12482	-163
10	7929	103	7090	69	34	1	950	66	2319	161
20	7826	103	7159	69	33	1	0-35016	66	2158	160
30	7723	104	7228	69	32	1	082	67	1998	158
40	7619	102	7297	68	31	1	149	67	1840	155
50	7517	106	7365	70	30	1	216	68	1685	154
28 0'	3-9957411	104	1-9977435	70	5-38029	1	0-35284	68	0-11531	152
10	7307	105	7505	70	28	1	352	68	1379	150
20	7202	107	7575	71	27	2	420	70	1229	149
30	7095	105	7646	70	25	1	490	69	1080	147
40	6990	106	7716	71	24	1	559	70	0993	144
50	6884	106	7787	71	23	1	629	71	0789	144
29 0'	3-9956778	107	1-9977857	72	5-38022	1	0-35700	71	0-10645	141
10	6671	107	7929	71	21	1	771	71	0504	140
20	6564	109	8000	73	20	1	842	72	0364	138
30	6455	108	8073	72	19	1	914	72	0226	136
40	6347	109	8145	73	18	1	986	73	0-10090	135
50	6238	110	8218	73	17	1	0-36059	74	0-09955	133
30 0'	3-9956128	108	1-9978291	72	5-38016	1	0-36133	74	0-09822	132
10	6020	109	8363	73	15	1	207	74	9690	130
20	5911	110	8436	73	14	1	281	75	9560	129
30	5801	110	8509	73	13	2	356	75	9431	127
40	5691	111	8582	74	11	1	431	75	9304	125
50	5580	112	8656	75	10	1	507	77	9179	124
31 0'	3-9955468	110	1-9978731	73	5-38009	1	0-36584	77	0-09055	122
10	5358	113	8804	76	08	1	661	77	8933	121
20	5245	111	8880	74	07	1	738	78	8812	120
30	5134	113	8954	75	06	1	816	78	8692	119
40	5021	112	9029	75	05	1	894	79	8573	116
50	4909	113	9104	75	04	2	973	80	8457	115
32 0'	3-9954796	114	1-9979179	76	5-38002	1	0-37053	80	0-08342	114
10	4682	114	9255	75	01	1	133	80	8228	113
20	4568	114	9330	76	00	1	213	81	8115	111
30	4454	114	9406	77	5-37999	1	294	82	8004	110
40	4340	115	9483	76	98	1	376	82	7894	108
50	4225	115	9559	77	97	1	458	82	7786	107
33 0'	3-9954110	115	1-9979636	77	5-37996	2	0-37540	83	0-07679	106
10	3995	116	9713	77	94	1	623	84	7573	105
20	3879	115	9790	77	93	1	707	84	7468	104
30	3764	117	9867	77	92	1	791	84	7364	102
40	3647	117	9944	77	91	1	876	85	7262	101
50	3531	116	1-9980022	78	90	1	961	85	7161	99
34 0'	3-9953414	117	1-9980100	78	5-37989	2	0-38047	86	0-07062	99
10	3297	117	0178	78	87	1	133	87	6993	97
20	3180	118	0256	78	86	1	220	87	6866	96
30	3062	117	0334	79	85	1	307	88	6770	95
40	2945	118	0413	79	84	1	395	88	6675	94
50	2827	119	0492	79	83	1	483	89	6581	93
35 0'	3-9952708	119	1-9980571	79	5-37982	1	0-38572	89	0-06488	93

CHAPTER XIX.

ON THE COMPUTATION OF HEIGHTS.

To compute the difference of height between two Trigonometrical Stations, the elements required are derived partly from observation, and partly from previous computation. Of the former class, are the vertical angles taken at one or both the stations, and the heights of the instrument and of the signals used. Of the latter class, are the distance at the sea level between the two stations, and the elevation of one of those stations above the same level.

The observation of a vertical angle is thus made: the Theodolite being placed over the centre of the eye station and properly levelled, an intersection is taken to the signal at the object station. The micrometers or verniers to the vertical circle, are now read off: the mean whereof constitutes one observation on one face. The telescope is now turned round 180° vertically as well as horizontally, and the same signal is intersected a second time. The vertical limb being then read off as before, we have the second observation on the opposite face. The mean of the two observations made on reversed faces will furnish, cleared of index and collimation error, the elevation or the depression at which the signal stands, as seen from the eye station.

When a vertical angle is observed, the time of the observation as well as the heights of the instrument and of the signal are noted in the Vertical Angle Book, a specimen of which is subjoined.

SPECIMEN OF THE VERTICAL ANGLE BOOK.

<i>Afternoon Vertical Angles taken at Shevalingapah Hill Station, 1st November, 1838.</i>									
Names of Places Observed.	Face.	Time of Observation.	Micrometer Readings.			Mean Vertical Readings.			Remarks.
			A	B		1 Face.	Both Faces.	General.	
Yemshaw Hel. ...	R	<i>h. m.</i> 5-49	0 15 29-5	0 15 21-0	0 15 25-25	0 15 25-25	0 15 25-40	0 15 25-24	Height of Instrument 62-4 Inches.
	L	5-52	0 15 27-0	0 15 24-1	0 15 25-55				Height of Heliotrope 22-8 Inches.
	L	5-55	0 15 25-3	0 15 23-9	0 15 24-60				
	R	5-58	0 15 29-9	0 15 21-2	0 15 25-55				
<i>Afternoon Vertical Angles taken at Yemshaw Hill Station, 7th November, 1838.</i>									
Shevalingapah Hel.	R	5-58	0 4 24-4	0 4 12-2	0 4 18-30	0 4 18-30	0 4 16-75	0 4 13-78	Height of Instrument 62-8 Inches.
	L	6-1	0 4 11-4	0 4 19-0	0 4 15-20				Height of Heliotrope 19-5 Inches.
	L	6-3	0 4 10-8	0 4 16-3	0 4 13-55				
	R	6-5	0 4 16-1	0 4 0-0	0 4 8-05	0 4 8-05	0 4 10-80		

By way of distinction the station whose height is given may be called the station *A*, the other whose altitude is required being styled the station *B*. It is also necessary to premise at this place that in the phraseology of the Trigonometrical Survey the distances at the sea level, such as those derived from a Trigonometrical operation, are called geodetic distances.

Certain preliminary considerations must now be attended to before the computation of height can be taken in hand. In the first place, the given geodetic distance will require to be converted into seconds. When this operation is performed, the resulting element is called the contained arc. The precept for making this deduction is as follows:—Add together the logarithm of the geodetic distance in feet, and the constant logarithm $\bar{3}\cdot9935154$, the natural number answering to the sum, is the contained arc in seconds.

EXAMPLE.

Take the distance from Yemahaw to Shevalingapah page 418.

Logarithm of the distance in feet,	5·1346620
Constant Log.,	<u>$\bar{3}\cdot9935154$</u>
Contained Arc = 1343"	<u>3·1281774</u>

Again the geodetic distance as it stands cannot be employed in the computation of height; it will require to be reduced to the level of station *A*. The formula given at page 390 could be easily altered to furnish this result, but as the logarithm of the distance is made use of in the computation, it is obviously more convenient to correct that term at once, which may be effected in the following manner:—

To the logarithm of the height in feet of station *A* above the sea level, add the constant logarithm $\bar{8}\cdot3168746$, the natural number answering to the sum, carried to 7 places of decimals is the logarithmic correction required.

EXAMPLE.

Height of Yemahaw above the sea level, 1463·3 feet, Log.,	3·1653334
	<u>Constant Log., $\bar{8}\cdot3168746$</u>
Logarithmic correction, 0·0000304	<u>5·4822080</u>

The logarithmic correction added to the logarithm of the geodetic distance, gives the logarithm of the distance at the level of station *A*.

$$\text{Thus. } \left. \begin{array}{l} 5.1346620 \\ + 0.0000304 \end{array} \right\} = 5.1346924 \quad \left\{ \begin{array}{l} \text{Log. of the distance from Yemshaw to} \\ \text{Shevalingapah at the level of the former.} \end{array} \right.$$

Again, that the computed height of a station may be available for any required use in future, it is necessary to refer that element to a permanent mark belonging to the station. In the Great Trigonometrical Survey of India, the upper station dot is taken as the point of reference. But the instrument with which the vertical angle is taken, as well as the signal observed, being elevated above that dot, it follows that the observed angle will stand in need of two corrections, of which the one arising from the height of the instrument or eye, is called the *eye* correction, while the other proceeding from the elevation of the signal or object observed, is styled the *object* correction.

The rules by which the corrections abovementioned may be computed are as follows :

To compute the eye correction.—Add together the logarithm of the height of the eye in inches, the arithmetical complement of the logarithm of the distance in feet at the level of station *A*, and the constant logarithm 4.2352439, the natural number answering to the sum is the correction in seconds, additive to an elevation, and subtractive from a depression.

EXAMPLE.

Height of the Instrument at Shevalingapah 62.4 inches,....	Log., 1.7951846
A. C. of Log., of distance at the level of Yemshaw,	4.8653076
	Constant Log., 4.2352439
"	
Eye correction, — 7.87.....	Log., <u>0.8957361</u>

To compute the object correction.—Add together the logarithm of the height of the object in inches, the arithmetical complement of the logarithm of the distance in feet at the level

of station *A*, and the constant logarithm 4·2352439, the natural number answering to the sum is the correction in seconds, additive to a depression, and subtractive from an elevation.

EXAMPLE.

Height of the signal at Yemshaw 22·8 inches,	Log.,	1·3579348
A. C. of Log. of distance at the level of Yemshaw,		4·8653076
	Constant Log.,	4·2352439
		<hr/>
Object correction + 2·87	Log.,	<u>0·4584863</u>

When the observed vertical angle, has received the eye and object corrections, the points to which it becomes referrible, are the upper station dots. The vertical angle so reduced is called the apparent vertical arc.

EXAMPLE.

Observed Vertical Angle at Shevalingapah,	D	0	15	25·24
Eye correction,	—			7·87
Object correction,	+			2·87
				<hr/>
Apparent Vertical Arc at Shevalingapah,	D	0	15	<u>20·24</u>

The problem of the computation of heights may be divided into the two following cases:—first, when vertical angles have been observed at the two stations *A* and *B*, and secondly, when a vertical angle has been taken at one of the stations only. We will now proceed to treat of the first case.

After the observed vertical angles at the two stations *A* and *B* have been reduced into apparent vertical arcs, an auxiliary angle, called the subtended angle, will next require to be computed, which is done in this way. When both the apparent arcs are depressions, take half the difference: when one only is an elevation, take half the sum: the result in either case is the subtended angle required.

EXAMPLE.

Apparent Vertical Arc at Shevalingapah,	D	0	15	20·24
Ditto ditto at Yemshaw,	D	0	4	8·32
				<hr/>
Subtended Angle,		0	5	<u>36·0</u>

By the aid of the subtended angle derived as directed above, the difference of height between the two stations is easily de-

ducible in the following manner. To the logarithmic sine of the subtended angle, add the log. secant of the vertical arc taken at station *B*, and the logarithm of the distance at the level of station *A*, the natural number answering to the sum, is the required difference of height between the two stations.

EXAMPLE.

Subtended Angle,	0 5 36	Log. Sin.,	7.2119140
Apparent Vertical Arc at Shevalingapah <i>D</i>	0 15 20	Log. Sec.,	0.0000043
Distance in feet at the level of <i>Yemshaw</i> ,		Log.,	5.1346924
Required difference of height in feet, 222.1		Log.,	<u>2.3466107</u>

Connected with the computation of heights is the important subject of terrestrial refraction; it is evident that every vertical angle observed is affected with that inequality. Its general effect is to raise an object above its true position; when two observed vertical angles are made use of in the computation of a height, although these angles are individually impregnated with refraction, they produce a result which is entirely free from that inequality. This arises from the peculiar combination of the observed vertical angles in the deduction of the subtended angle, whereby the refraction in one angle, is cancelled by that in the other.

There is, however, only one condition required to produce this cancelment, namely, an equality of the amounts of refraction in the two observed vertical angles. That this equality may obtain in practice, vertical angle observations at the reciprocal stations should be made under as nearly as possible the same atmospheric conditions. When two observers and two instruments are available, they are best taken simultaneously, but in cases in which this cannot be resorted to, the observations ought to be made contemporaneously, that is, at the same time on different days, these days being separated by as small an interval as possible.

Experience has shewn that the best time for observing a set of vertical angles is between the hours of 2 $\frac{3}{4}$ and 3 $\frac{1}{4}$ from apparent noon. When vertical angles have been taken with due

regard to the conditions above specified, the precepts whereby the amount of refraction involved in them, may be computed, are as follows:

Take the sum of the reciprocal apparent vertical arcs when they are both depressions, or their difference when one is an elevation, subtract the sum or difference so derived from the contained arc, half the remainder is the amount of terrestrial refraction required.

EXAMPLE.

	°	'	"
Apparent Vertical Arc at Shevalingapah,	D 0	15	20.24
Ditto ditto at Yemshaw,	D 0	4	8.32
<hr style="width: 100%;"/>			
Which being both depressions are added together, and their sum in seconds is,			1169
Contained arc in seconds,.....			1343
<hr style="width: 100%;"/>			
Half the difference or terrestrial refraction,.....			<u>87</u>

It is a practice with the geodetic writers to express the refraction in decimals of the contained arc, this reduction may be performed as follows:

Reduce the terrestrial refraction and the contained arc to seconds, divide the former by the latter, the quotient is the value of the terrestrial refraction in the decimals of the contained arc.

EXAMPLE.

Thus in the case of Yemshaw and Shevalingapah, the refraction being 87", and the contained arc 1343", we shall have $\frac{87''}{1343} = .065$, for the value of the refraction in decimals of the contained arc.

It now remains to explain Case 2nd, or the method of computing the difference of heights between two stations from a vertical angle taken at one of them only. The observed vertical angle being corrected for the heights of the instrument and signal, as well as for refraction,* we shall have the value

* There are no fixed rules for Terrestrial refraction, but it is generally taken at $\frac{1}{15}$ of the contained arc.

of the vertical angle, as if it were taken in vacuo at the station of observation.

Now the contained arc is equal to the sum of the two vertical angles in vacuo, when they are both depressions, or to the difference between them when one is an elevation, which relation gives the following simple precepts for computing the vertical angle in vacuo, at the object station. When the vertical angle in vacuo at the eye station is a depression, take the difference between it and the contained arc: when it is an elevation take their sum, the resulting element in either case, is the vertical angle in vacuo at the object station.

To determine whether the last deduced vertical angle is an elevation or a depression, the considerations which will require to be attended to, are three in number and they are as follows :

First, when the vertical angle in vacuo at the eye station is a depression, and less than the contained arc ; second, when it is a depression and greater than the contained arc ; and third, when it is an elevation.

In the first and third cases, the resulting vertical angle at the object station is a depression, and in the second, it is an elevation.

Having obtained the two vertical angles in vacuo, treat them as if they were apparent vertical arcs, and deduce therefrom the subtended angle, and the difference of height, as in Case 1st. To exemplify this computation, take the deduction of Himalaya snowy peak α from Amsot Hill station :

	°	'	"
Observed vertical angle at Amsot,	E 2	20	45.93
Eye correction,		+	3.12
Object correction is evanescent, the top of the peak being observed, .....		..	. 0.00
Refraction taken at $\frac{1}{3}$ of contained arc,		-	3 49.26
Vertical angle in vacuo at Amsot,	E 2	16	59.79
Which being an elevation, will require to be augmented by the contained arc,		0	57 18.90
Vertical angle in vacuo at snowy peak α	D 3	14	18.69

FORM FOR REGISTERING THE COMPUTATION OF THE HEIGHT OF A TRIGONOMETRICAL STATION.

D. Day N. Night Observation.	Eye Stations.	Object Stations.	Observed Vertical Angles.	Log. of the Geodetic Distances.	Logarithmic Corre- tion Additive.	Contained Arc.	Object Cor- rections.		Eye Cor- rections.		Apparent Vertical Arc.	Terrestrial Refraction.		Heights Deduced.		
							Inches.	Angle.	Inches.	Angle.		Seconds.	Decimal of contained Arc.	Compa- rative.	Above the Sea Level.	
D	Sheva- linga- pah, .. Yemsha,	Yemsha, Sheva- linga- pah, ..	D 0 15 25-24 D 0 4 13-78 5-1346620 304 1343	22-8	+ 2-87	62-4	- 7-87	0 15 20-24 D 0 4 8-32	87	-065	0 5 36-0	+ 222-1	Shevalinga- pah, 1685-4 feet
<i>Shevalingapah deduced from Yemsham.</i>																
<i>Himalaya Snowy peak a deduced from Amsot Hill Station.</i>																
D	Snowy peak a, Amsot,	Amsot, Snowy peak a	..... E 2-20 45-98	..... 5-5429020	..... 675 3438-9	..... .....	.....	.....	.....	.....	D 3 14 18-69 E 2 16 59-79	- 220-26	2 45 39-2	+ 10842-8	Snowy Peak { a, 20065-1 feet
																Height of Amsot above the sea level = 3252-3 feet.

CHAPTER XX.

ON MINOR TRIANGULATION, AND THE SAME AS APPLIED TO THE RAY TRACE SYSTEM, FOR CARRYING ON TOPOGRAPHICAL SURVEYS.

AFTER having explained the approved principles of observation and computation, as generally practised in a Trigonometrical Survey, we will now proceed to shew their application to the detail survey of a district.

The primary triangles of a Topographical Survey may be thrown into the form of a network as shewn in Fig. 1, or into that of a gridiron exhibited in Fig. 2. Plate 7 B. Of these two forms the gridiron is preferable to the network, in the first place, because it contains a smaller number of triangles and is more scientific; and secondly, because it is susceptible of a more systematic deduction than the other. This mode of distribution however, will be found more difficult in most hilly countries than the common network, and occupy a longer time than is generally allotted to Topographical Surveyors, but whatever form may be given to the primary triangles of a Topographical Survey, there is one condition, namely, that of symmetry, which ought to be strictly adhered to in their selection. In no case should a triangle of a primary character be admitted, any of whose angles falls short of 30° or exceeds 90° as before stated at page 393.

The sides of these primary triangles should average between two and five miles, and the best instrument for executing this description of work is a 12-inch Theodolite. The

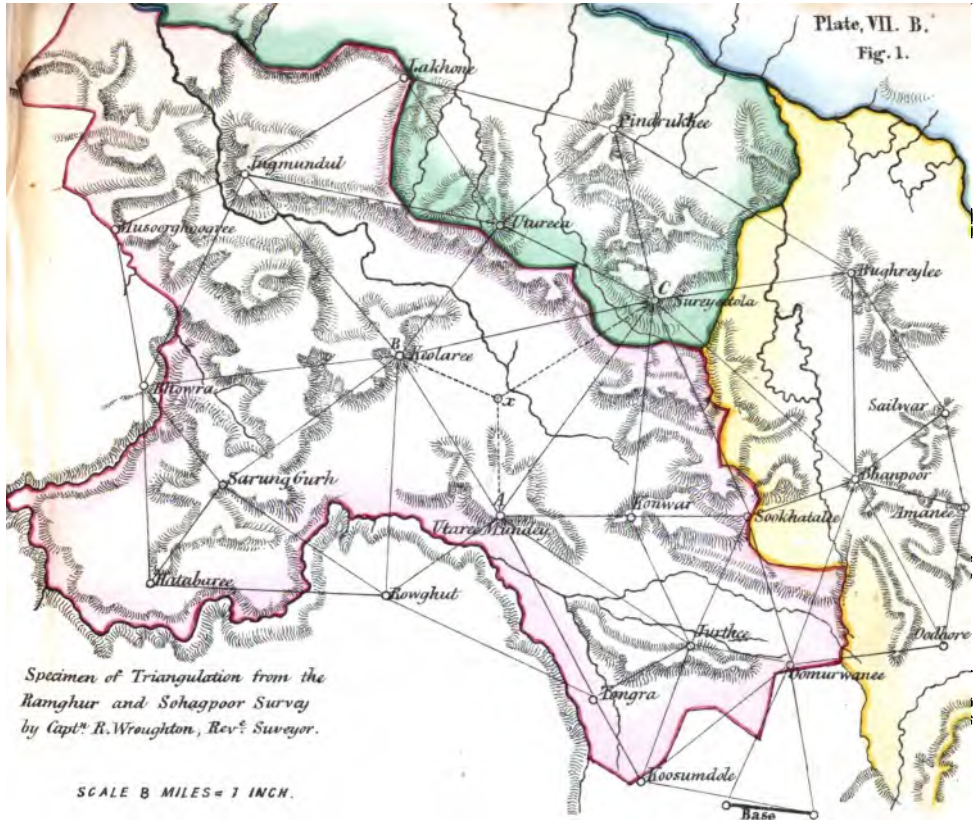
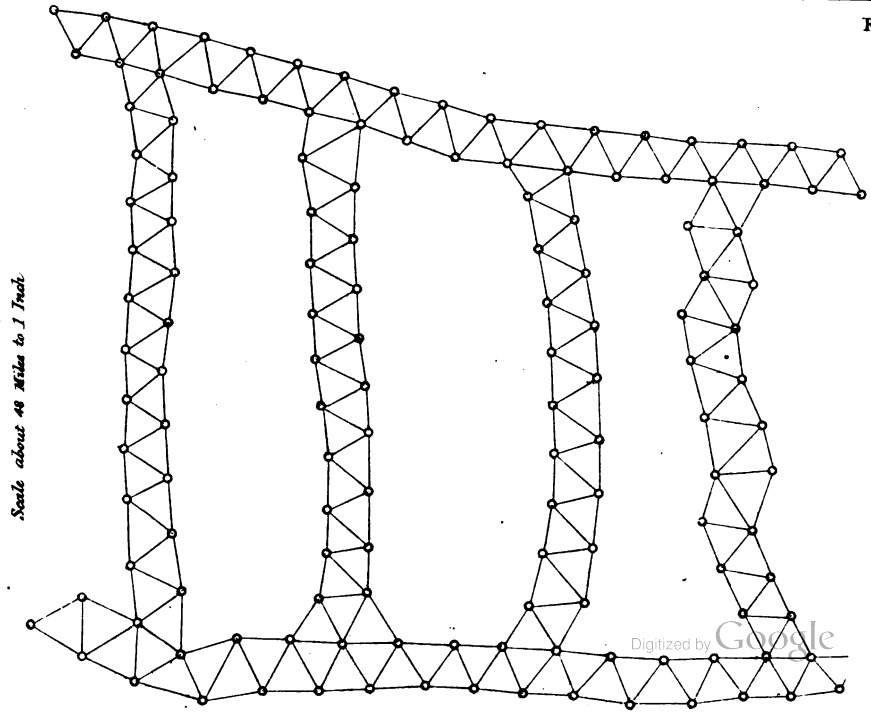


Fig. 2



three angles of a primary triangle ought in every instance to be observed, every angle being measured on two zeros 0° and 30° with their reversed faces as before described. As to computation, these triangles may be treated as *plane*, the spherical excess being in their case, an unappreciable quantity, the angles used, being taken to the nearest second.

With due regard to these precautions, the primary triangulation of a district being executed, the next thing to be taken in hand is the collection of the Topographical details, which may be done in the following manner.

If the point x Plate 7 B. which we shall suppose to be the site of a village, be observed from two primary stations A and B , we shall have the triangle ABx giving the position of the last mentioned point. Again, if x happen to be observed from three primary stations as A , B , and C , the triangles formed will be three in number, namely, 1st $\triangle ABx$, 2nd $\triangle ACx$, and 3rd $\triangle BCx$. Now, here are three distances Ax , Bx and Cx , which are respectively possessed of two values, the first being derived from \triangle s 1 and 2, the second from \triangle s 1 and 3, and the third from \triangle s 2 and 3. These double values being compared, the discrepancies (if any) will indicate the amount of confidence to be attached to the result.

The point x fixed in the way described above is called an intersected point. For the reasons already stated, a point of this kind should be determined whenever it is practicable, by two triangles possessing a common side.

In the case of the intersected points, the symmetry of the triangles cannot be so rigorously attended to as in the instance of the primary stations, because such points must be observed from wherever they are visible. Here, however, a small error in a given position would be attended with no inconvenience, as it would not extend beyond the site to which it appertains. It has been found, in practice, that triangles whose angles range between 15° and 150° furnish trustworthy results. The angles to intersected points should be

observed on zero 0° and on its reversed face, the observation in each case being repeated twice to check the readings of the instrument as well as the record thereof.

Some attention must be paid to the signals used:—if they are large undefined objects, as whole bodies of villages, &c., they will be unsusceptible of accurate intersection, and will therefore produce discordant results. The kalus of a mosque, or of a temple, church spire, tops of columns, &c., form good objects for intersection, but these are seldom to be met with, and in their absence flags may be used, which may either be placed on the ground, or fastened to tops of high trees, as may be convenient. Tree flags have been tried in the Great Trigonometrical Survey and found to answer well.

It is clear that most of the villages in a district, as well as all the prominent marks on the boundary line, could be laid down as intersected points: the few villages that cannot be so determined, may be fixed by a measured angle and distance from a primary station. The sides of the secondary triangles should be carried as near the boundary of the subdivision or pergunnah circuits as possible, in cases where a Revenue Survey is required, but this of course will depend on the natural features of the country. On any of the sides of these, the Plane Table and Cross Staff is applied and the intervals are filled up by sketching, and a series of perpendicular lines are thus made to traverse the Topographical details. The more minutely the triangulation has been carried on, the easier and more correct will be the interior filling up, whether entirely by measurement with the Chain, or only partially so, and the remainder completed by sketching. The Plane Table is the best contrivance for this purpose, and the process of sketching between the fixed points plotted on the paper, is similar to surveying with the Chain and Theodolite as far as the natural and artificial boundaries are concerned. Every thing being at once drawn on the paper instead of

being entered in a Fieldbook, the features of the ground are sketched at the same time as the boundaries and other details. This part of the operation, however, requires much practice before any thing like facility of execution can be acquired.

The Plane Table is made in a variety of ways, but to render it really useful it should be reduced to the most simple state possible, and as light as can be consistent with strength and steadiness. The English manufacture with the box-wood scale frame, as described at page 115, is quite unsuited to the heat and hot winds of this climate; they warp, and go to pieces immediately, but the pattern now in use, as made up in the Mathematical Instrument Department, Calcutta, of the best seasoned teak wood, is a simple square board, without any shifting frame, with the fiducial edge ruler of ebony clamped with brass, the Sight, being affixed at each end, and compass box sliding underneath, of the same metal, the Table fixing on the braced tripod stand, by means of a clamping screw under it.

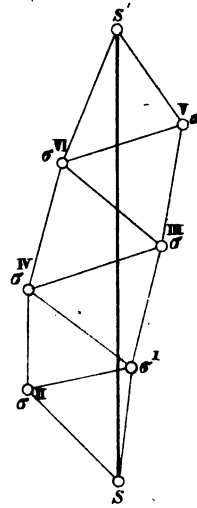
Every two points of a Survey, whatever objects may be between them, will in fact be the extremities of a base equally true as if it had been actually measured; and the Table being placed on such points, and adjusted by means of the legs, and the needle, which answers instead of a level, where the greatest accuracy in fixing the instrument horizontally is not required, we obtain intersections to all objects of which it may be necessary to find the place. This is done by placing the leg of a pair of compasses upon the station and the edge of the ruler in contact with it, turning the ruler as upon a pivot, until the object to be intersected is seen along its edge, and then drawing a fine line by the same edge. This being done from three different places, will be found very exact in most cases, although there is in strictness, an error of the same kind as that mentioned in treating of the Theodolite, when it is not

exactly over a station; but this nicety is of little consequence, for the Table, being but small, the difference occasioned by the eccentricity of the instrument, can never make many inches error in the position of an object, and upon almost all scales in common use, this magnitude is but a mere point. Thus we may join up any unfinished lines, that were left in surveying to avoid short stations, or for other reasons.

When the method of surveying the interior details is rigidly carried out, there is nothing left to be sketched in, except the contours of the ground which do not present marked features to which measurement can be applied. The comparative heights, however, obtained by levelling with the Theodolite during the Survey, present so many certain points of reference as to the relative command of the ground, and are of course of the greatest assistance in the subsequent delineation of the features upon the outline plan. When the inequalities of the surface of any particular portions, require to be shown more in detail, recourse must be had to a regular process of Levelling and Contouring, both of which subjects are treated of in separate Chapters.

With a view of adapting the triangulation of a district convenient for this purpose, suppose a series of principal triangles of the Great Trigonometrical Survey to have been carried through a district, it is evident that the sides of those triangles ranging from ten to twenty miles, cannot as they stand be immediately made use of in a Topographical Survey, in which bases of two to five miles only are required. To resolve therefore a side of a principal triangle into a convenient number of small distances of the required lengths, the Ray Trace System by minor triangulation may be resorted to, with great advantage. We will now proceed to explain the method.

Let S and S' be two stations of the Trigonometrical Survey. Taking S as an origin, select a series of small triangles along the given line SS' until the other extremity S' is reached, and is connected therewith; these triangles must be treated as primary triangles of a detail operation. Their computation may be performed as follows; on reference to the diagram it will be seen that there are two lines $S\sigma'$ and $S\sigma''$ connected with the origin S , assuming either of these as unity, the remaining sides of the triangulation may be deduced in terms thereof.



It is evident that if the whole distance SS' can be obtained in terms of the same measure, the deduction of the true values of the sides of the minor triangulation may be easily effected by the following rules of proportion:

- As the hypothetical value of the line SS' (ρ).
 : The true trigonometrical value thereof (R).
 :: The hypothetical value of the side.
 : Its corresponding trigonometrical length.

To determine the hypothetical value of the side SS' the method of computation explained at pp. 374 to 377 will require to be resorted to. Take the series of sites on the right or left flank of the minor triangulation as may be convenient, and consider them as the stations of a Route Survey. The elements which will be required for the deduction of either of the flanking lines taken as a route are the distances and angles.

The distances to be used are the hypothetical distances derived as described above on the assumption of one of the two first sides of the minor triangulation taken as unity.

The angle at any site of the minor triangulation taken as a Route Survey Point, is determined in this way. Suppose an observer to be placed at the given site looking in the

direction of the rear Station, let him turn round towards his right until he faces the point in advance; the horizontal arc which his eye will describe during this operation is that which will be required in the Ray Trace deduction. A reference to the sketch of the minor triangulation, will indicate the process of deriving the arc from the angles of the primary triangles. The only circumstance to be attended to in this computation is, that the angles used, must be those which have been adjusted to 180° .

Computing the arcs abovementioned for the several sites on the right or left flank, (as the case may be) of the minor triangulation, and calling them in the order in which they stand $\angle s \odot_1, \odot_2, \odot_3, \dots$ of the Route Survey, deduce therefrom the angles for computation $A, B, C \dots$ as detailed in Chapter 15.

With these angles for computation and the hypothetical distances, the co-ordinates $x' x'' x''' \dots$ and also $y', y'', y''' \dots$ being deduced, the whole line SS' may be derived in terms of the first side of the minor triangulation.

The hypothetical value of the line SS' being determined and its true value having been previously derived from the Trigonometrical Survey, the true lengths of the sides of the minor triangulation can be ascertained by the rule of proportion given before.

The angles θ and θ' of p. 377 derived from this computation, are useful in determining the azimuths of the first and last sides of the minor triangulation. For instance, the azimuth of the line $S\theta' = A - \theta$, A being the azimuth of S' from S . Similarly calling B the back azimuth of S from S' , the azimuth of the last line will be $B - \theta'$. With these azimuths, the geographical position of S and S' being given, the latitudes and longitudes of the stations of the minor triangulation may be deduced.

To illustrate the computation of a Ray Trace by minor triangulation take the following example from the Report of the Great Trigonometrical Survey of India.

Tracing of Ray Dahera to Nohali by Minor Triangulation executed by Babu Radhanath Sikkhar, Sub-Assistant Great Trigonometrical Survey, with a 12-inch Theodolite of the East India Company's Pattern, in the year 1840.

Names of Stations.	Observed Angles.	Apportionment of Error.	Corrected Angles.	Log. Sines.	Hypothetical Distances.	True Distances in		
						Feet.	Miles.	
No. 1 Dahera to Rankandi— Hypothetical Dist. Log. 0·000000 True Dist. in feet Log. 4·0145561.								
Dahera,	65 25 46·8	+ 5·8	65 25 53	9·9587855	1·451905	15013·9	2·844	
Rankandi,	73 17 30·4	+ 5·8	73 17 36	9·9812699	1·378650	14256·4	2·700	
Station 3,	41 16 25·4	+ 5·8	41 16 31	9·8193316	Logs.	Logs.		
	179 59 42·6	+ 17·4	180 0 0		0·1619383	4·1764944		
2 Dahera to Station 3— Hypothetical Dist. Log. 0·1619383 True Dist. in feet Log. 4·1764944.								
Dahera,	68 18 49·8	— 3·8	68 18 40	9·9681112	1·806980	18685·7	3·539	
Station 3,	64 58 7·6	— 3·8	64 58 4	9·9571617	1·853118	19162·8	3·629	
Barheri,	46 43 19·9	— 3·7	46 43 16	9·8621465	Logs.	Logs.		
	180 0 11·3	— 11·3	180 0 0		0·2569535	4·2715096		
3 Barheri to Station 3— Hypothetical Dist. Log. 0·2679030 True Dist. in feet Log. 4·2824591.								
Barheri,	57 40 36·4	+ 2·1	57 40 38	9·9268821	1·708709	17669·5	3·346	
Station 3,	56 56 58·8	+ 2·0	56 57 1	9·9233464	1·722677	17813·9	3·374	
Labkari,	65 22 18·6	+ 2·1	65 22 21	9·9585812	Logs.	Logs.		
	179 59 53·8	+ 6·2	180 0 0		0·2326682	4·2472243		
4 Barheri to Labkari— Hypothetical Dist. Log. 0·2326682 True Dist. in feet Log. 4·2472243.								
Barheri,	65 36 13·6	— 2·7	65 36 11	9·9593781	1·966310	20333·3	3·851	
Labkari,	63 24 22·3	— 2·6	63 24 20	9·9514335	2·002611	20708·7	3·922	
Station 4,	50 59 32·0	— 2·6	50 59 29	9·8904497	Logs.	Logs.		
	180 0 7·9	— 7·9	180 0 0		0·2996520	4·3082081		
5 Labkari to Station 4— Hypothetical Dist. Log. 0·3015966 True Dist. in feet Log. 4·3161527.								
Labkari,	51 6 9·6	+ 2·9	51 6 12	9·8911357	1·852150	19152·8	3·627	
Station 4,	59 46 47·8	+ 2·9	59 46 51	9·9365673	1·668186	17250·5	3·267	
Paka Well,	69 6 53·8	+ 3·0	69 6 57	9·9704378	Logs.	Logs.		
	179 59 51·2	+ 8·8	180 0 0		0·2676761	4·2823222		
6 Station 4 to Paka Well— Hypothetical Dist. Log. 0·2222445 True Dist. in feet Log. 4·2369006.								
Station 4,	59 41 44·1	+ 0·3	59 41 44	9·9361901	1·572081	16256·7	3·079	
Paka Well,	57 11 35·5	+ 0·2	57 11 36	9·9245396	1·614826	16698·7	3·163	
Pirer,	63 6 39·6	+ 0·3	63 6 40	9·9503090	Logs.	Logs.		
	179 59 59·2	+ 0·8	180 0 0		0·1964751	4·2110312		
7 Paka Well to Pirer— Hypothetical Dist. Log. 0·2081256 True Dist. in feet Log. 4·2226817.								
Paka Well,	51 7 33·4	+ 0·3	51 7 34	9·8912749	1·819305	18813·2	3·563	
Pirer,	71 31 58·1	+ 0·3	71 31 58	9·9770396	1·493279	16441·8	2·925	
Paniari,	57 20 27·6	+ 0·3	57 20 28	9·9252596	Logs.	Logs.		
	179 59 59·1	+ 0·9	180 0 0		0·2599056	4·2744617		
						0·1741409	4·1886970	

Names of Stations.	Observed Angles.	Apportionment of Error.	Corrected Angles.	Log. Sines.	Hypothetical Distances.	True Distances in	
						Feet.	Miles.
No. 8 Pirer to Paniari— Hypothetical Dist. Log. 0.1741409 True Dist. in feet Log. 4.1899870.							
Pirer,	53 26 57.5	+ 1.4	53 26 59	9.9048965	1.686672	17441.6	3.308
Paniari,	70 9 44.0	+ 1.5	70 9 45	9.9734322	1.440439	14895.4	2.821
Mirpur,	56 23 14.2	+ 1.4	56 23 16	9.9205424	0.2270307	4.2415868	
	179 59 55.7	+ 4.3	180 0 0		0.1584950	4.1790511	
9 Paniari to Mirpur— Hypothetical Dist. Log. 0.1584950 True Dist. in feet Log. 4.1790511.							
Paniari,	65 24 22.5	+ 2.0	65 24 24	9.9586998	1.546149	15988.5	3.028
Mirpur,	60 27 4.7	+ 2.0	60 27 7	9.9394905	1.816071	16711.5	3.166
Station 5,	54 8 26.8	+ 2.0	54 8 29	9.9087343	0.1892512	4.2038073	
	179 59 54.0	+ 6.0	180 0 0		0.2084605	4.2230166	
10 Mirpur to Station 5— Hypothetical Dist. Log. 0.2084605 True Dist. in feet Log. 4.2230166.							
Mirpur,	69 43 45.7	+ 1.9	69 43 48	9.9722355	2.091916	21632.2	4.097
Station 5,	65 34 16.3	+ 1.8	65 34 18	9.9592701	2.155310	22287.7	4.221
Subri,	44 41 52.5	+ 1.8	44 41 54	9.8471863	0.3205443	4.3351004	
	179 59 54.5	+ 4.5	180 0 0		0.3335097	4.3480658	
11 Station 5 to Subri— Hypothetical Dist. Log. 0.3335097 True Dist. in feet Log. 4.3480658.							
Station 5,	56 59 19.4	+ 4.9	56 59 24	9.9235422	1.621567	16768.4	3.176
Subri,	46 54 42.0	+ 4.8	46 54 47	9.8635120	1.861938	19254.0	3.647
Nojhili,	76 5 44.0	+ 4.9	76 5 49	9.9870867	0.2099350	4.2244911	
	179 59 45.4	+ 14.6	180 0 0		0.2699652	4.2845213	

TYPE OF CALCULATION OF RAY DAHERA TO NOJHILI.

Distances.		Angles.	
		° ' "	
Dahera to Station 3,	$\alpha = 1.451905$	At Station 3,	$\odot 1 = 121 \ 55 \ 5$
Station 3 to Labkari,	$a = 1.722877$	„ Labkari,	$\odot 2 = 179 \ 52 \ 53$
Labkari to Paka Well,	$b = 1.852150$	„ Paka Well,	$\odot 3 = 177 \ 28 \ 7$
Paka Well to Paniari,	$c = 1.819305$	„ Paniari,	$\odot 4 = 192 \ 54 \ 37$
Paniari to Station 5,	$d = 1.546140$	„ Station 5,	$\odot 5 = 176 \ 42 \ 11$
Station 5 to Nojhili,	$e = 1.621567$		

Hence the angles for computation are as follows:

$$\begin{aligned}
 A &= 121 \ 55 \ 5 \\
 B &= (121 \ 55 \ 5 + 179 \ 52 \ 53 - \pi) = 121 \ 47 \ 58 \\
 C &= (121 \ 47 \ 58 + 177 \ 28 \ 7 - \pi) = 119 \ 14 \ 5 \\
 D &= (119 \ 14 \ 5 + 192 \ 54 \ 37 - \pi) = 132 \ 8 \ 42 \\
 E &= (132 \ 8 \ 42 + 176 \ 42 \ 11 - \pi) = 128 \ 50 \ 53 \\
 A &= 121 \ 55 \ 5 \text{ Cos. } 9.7232141 & \text{ Sin. } 9.9289090 \\
 a &= 1.722877 \text{ Log. } 0.2362039 & \text{ Log. } 0.2362039 \\
 & \sqrt{9594180 \dots + 910789} & \sqrt{0.1650119 \dots - 1.462317}
 \end{aligned}$$

$B = 121\ 47\ 58$ Cos. $9\ 7217674$ $b = 1\ 852150$ Log. $0\ 2876761$ <hr style="width: 100%;"/> $\overline{1\ 9884435} \dots + 0\ 975996$	Sin. $9\ 9263667$ Log. $0\ 2876761$ <hr style="width: 100%;"/> $0\ 1970428 \dots - 1\ 574138$
$C = 119\ 14\ 5$ Cos. $9\ 6987655$ $c = 1\ 819305$ Log. $0\ 2599056$ <hr style="width: 100%;"/> $\overline{1\ 9468711} \dots + 0\ 868528$	Sin. $9\ 9408283$ Log. $0\ 2599056$ <hr style="width: 100%;"/> $0\ 2007339 \dots - 1\ 587574$
$D = 132\ 8\ 42$ Cos. $9\ 8287284$ $d = 1\ 546149$ Log. $0\ 1892512$ <hr style="width: 100%;"/> $0\ 0159796 \dots + 1\ 037480$	Sin. $9\ 8700613$ Log. $0\ 1892512$ <hr style="width: 100%;"/> $0\ 0568325 \dots - 1\ 146390$
$E = 128\ 50\ 53$ Cos. $9\ 7974457$ $e = 1\ 621567$ Log. $0\ 2096350$ <hr style="width: 100%;"/> $0\ 0078907 \dots + 1\ 017140$	Sin. $9\ 8914327$ Log. $0\ 2096350$ <hr style="width: 100%;"/> $0\ 1018877 \dots - 1\ 262996$

$$\alpha = + 1\ 451905$$

Sum of Direct Co-ordinates, $x = 6\ 281828$	Sum of Perpr. Co-ords. $y = -7\ 033215$
Sum of Direct Co-ordinates, $x = 6\ 281828$	Log. $0\ 7980861$
	A. C. $9\ 2019139$
Sum of Perpr. Co-ordinates, $y = 7\ 033215$	Log. $0\ 8471639$
	Tan. $0\ 0460678$
	Sec. $0\ 1764320$
Sum of Direct Co-ordinates, $x = 6\ 281828$	Log. $0\ 7980861$
Nojhili to Dahera by Ray Trace Computation, Log.	$0\ 9745181$
Ditto by Trigonometrical Survey, Log.	$4\ 9890741$
Constant Log. of Correction,	$4\ 0145560$

This constant logarithm added to the logarithms of the distances derived from the Ray Trace Computation, will furnish the logarithms of the same distances, in terms of the unit of the Trigonometrical Survey.

θ Computed.

From which deduct E or last	$\pi - \theta =$	131 46 12.5
for Computation,	}	128 50 53.0
	$\theta' =$	<u>2 55 19.5</u>

Deduction of the Azimuths.

At Dahera, Azimuth of Nojhili A =	° ' "	190 51 40.9
	$\theta = -$	48 13 47.5
Azimuth of Station 3, $(A - \theta) =$		<u>239 5 28.4</u>
At Nojhili, Azimuth of Dahera	B =	10 53 24.5
	$\theta' = +$	2 55 19.5
Azimuth of Station 5 $(B - \theta') =$		<u>7 58 5.0</u>

A sketch of the foregoing Ray Trace, as well as of two others connected therewith, completing a principal triangle of the Great Trigonometrical Survey is given in plate VII A. On reference to this sketch it will be perceived that the triangulation originating from Dahera proceeds along the ray to Nojhili, whence it extends in the ray to Godhna and thence returns and closes in, at Dahera.

Each of these Ray Traces being deduced by an independent computation it is evident that the sides whereby these operations are connected with one another, will possess double values, which when compared will obviously indicate the degree of accuracy attained by the work. There are three sides of this description belonging to the minor triangulation in the sketch, and they are as follows:

1st.—*Nojhili to Station 5.*

Feet.	
16768·4	Deduced from Ray Dahera to Nojhili.
16771·0	„ „ Nojhili to Godhna.
<hr/>	
2·6	Error in the Triangulation.

2nd.—*Godhna to Station 10.*

Feet.	
29034·2	Derived from Ray Nojhili to Godhna.
29034·0	„ „ Godhna to Dahera.
<hr/>	
0·2	Error in the Triangulation.

3rd.—*Dahera to Barheri.*

Feet.	
18682·6	Deduced from Ray Godhna to Dahera.
18685·7	„ „ Dahera to Nojhili.
<hr/>	
3·1	Error in the Triangulation.

It will be seen that the primary triangles appertaining to the three Ray Traces are 32 in number. Taken by themselves, they are of no value, as they furnish little or no topographical information: they become valuable only, when they are made the basis for laying down village sites and other geogra-

77° 40' East of Greenwich

77° 50'

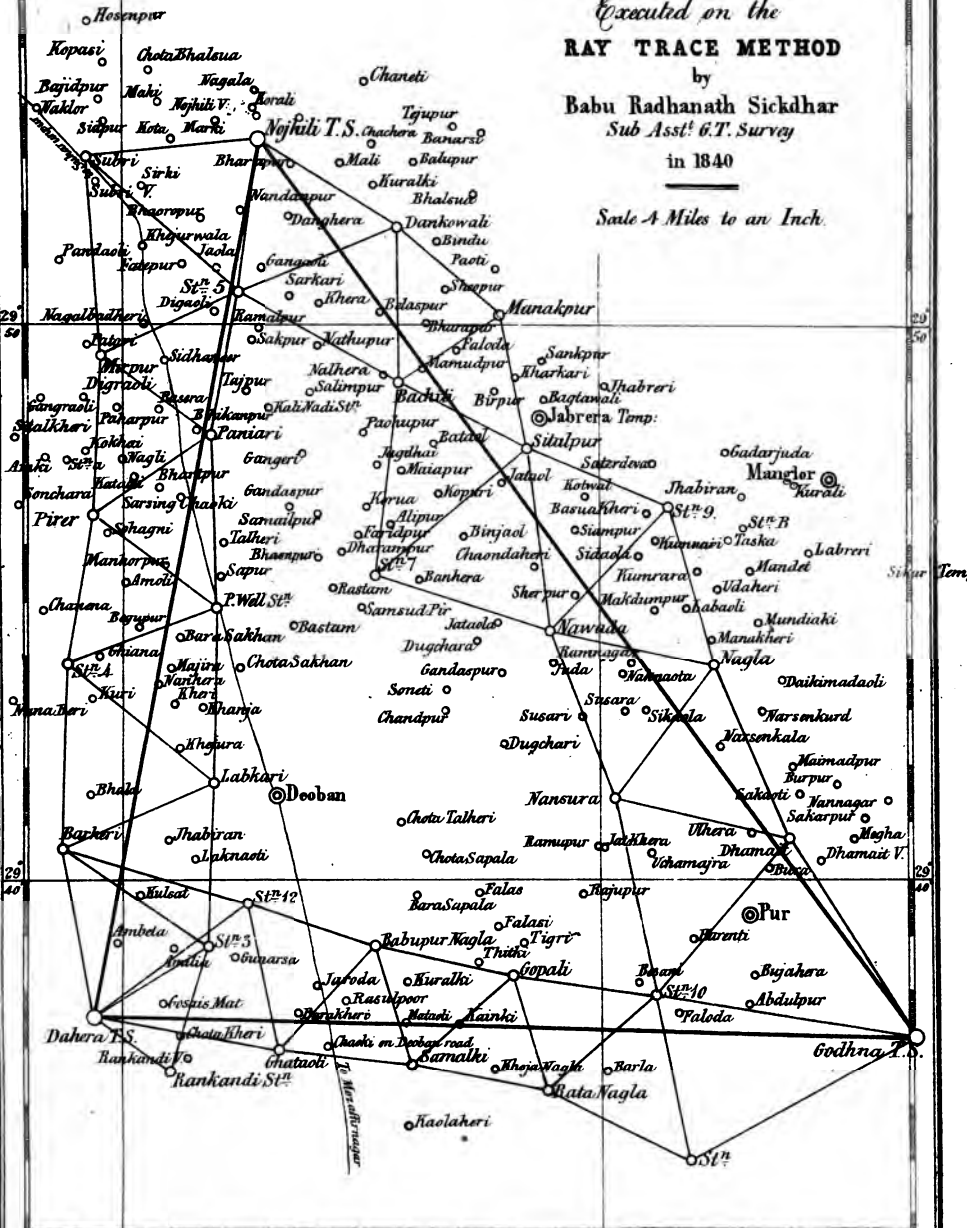
SKETCH

of a

MINOR TRIANGULATION
Executed on the
RAY TRACE METHOD

by
Babu Radhanath Sickdhar
Sub Asst^t G.T. Survey
in 1840

Scale 4 Miles to an Inch.



77° 40'

77° 50'

phical points of which the number determined by the triangulation under consideration is 190, and from the sides of these triangles, as bases, any description of Theodolite and Chain, Plane Table, or Compass Surveying according to the ordinary method, may emanate for the perfection of the general details.

Many of these points are fixed by two, some by three, and a few again by so many as four triangles. The common sides presented by this process never exhibit a discrepancy, exceeding a foot per mile.

We will conclude this chapter by giving the computation of a village site fixed by three independent triangles.

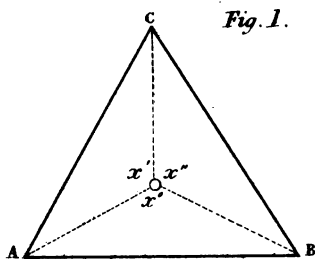
No.	Names of Stations.	Intersected Objects.	Angles for Computation.	Log. Sines.	Distances in	
					Feet.	Miles.
<i>Paniari to Mirpur = 14895.4 feet Log. 4.1730511 Miles 2.821 (Δ 8.)</i>						
Paniari.	Flag on the highest tree in Village.		23 16 15	9.5966828	9706	1.838
Mirpur.			32 40 18	9.7322523	7103	1.345
Sidhanser.			124 3 27	9.9182799	Logs.	
			180 0 0		3.9870235	
				3.8514540		
<i>Mirpur to Station 5 = 16711.5 feet Log. 4.2230166 Miles 3.165 (Δ 9.)</i>						
Mirpur.	Ditto.		27 46 47	9.6684544	7103	1.345
Station 5.			17 36 53	9.4808902	10940	2.072
Sidhanser.			134 36 20	9.8524543	Logs.	
			180 0 0		3.8514525	
				4.0390167		
<i>Station 5 to Paniari = 15988.5 feet Log. 4.2038073 Miles, 3.028 (Δ 9.)</i>						
Station 5.	Ditto.		36 31 30	9.7746436	10940	2.072
Paniari.			42 8 8	9.8266493	9705	1.838
Sidhanser.			101 20 22	9.9914385	Logs.	
			180 0 0		4.0390181	
				3.9870124		

CHAPTER XXI.

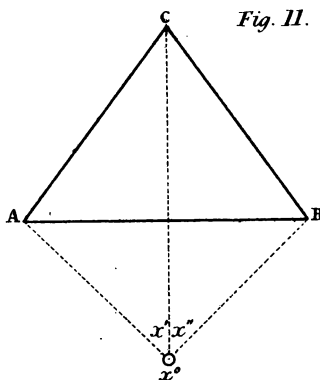
ON THE DETERMINATION OF THE POSITION OF A POINT FROM OBSERVATIONS MADE THEREAT, TO THREE KNOWN STATIONS, AND THE REDUCTION OF ANGLES TO THE CENTRE OF A STATION.

THE problem of fixing a Station by observations to three known points, has been extensively used in rough hilly countries, especially by the late Captain Wroughton, in the Sohagpore and Ramghur Territory. The mathematical part of this problem is old enough, but it is not an easy matter to compute. The geometrical construction has already been given at page 79, but as that does not readily suggest a convenient mode of computation, the following formula has been computed for the more rapid deduction of the problem. It is necessary that a Surveyor should have these rules, in case of accident, from having no other data, and from the necessity sometimes to bring up the work of others. As a *system*, however, observations to three points are unsatisfactory and lazy, the method is unsusceptible of minute accuracy, and there is no check; unless four points are observed, large errors may creep in, from mistakes in record, or in mistaking the

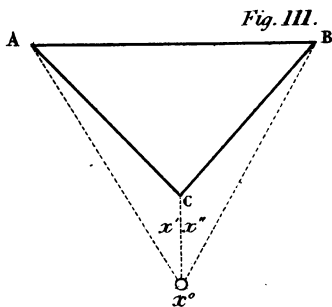
Stations. The observer has only to go up one of the three known points, and observe back to the Station requiring to be fixed, and the case then becomes an affair of simple triangles checked by common sides, and this should always be done by a careful Surveyor. The rule is, if a point depends on a single triangle, all three angles should be observed—if only two angles in a triangle can be observed, there should be at least two triangles to give a common side and thus check the accuracy of the determination, as adverted to at page 439.



The position of each village may be thus determined, by ascertaining the value of the angles subtended from it to three points of the surrounding secondary triangles, the azimuth of the lines connecting the latter give the azimuth of any of the lines of the subtended angles from the points in question.



In the annexed diagrams *A*, *B* and *C* are the three given Stations. Forming *A*, *B* and *C* into a triangle, designate the angles thereof by the letters which mark the Stations; the sides opposite thereto being represented by the corresponding small letters of the alphabet



a, b, c . It is evident that the angles A, B and C as well as the sides a, b and c are known elements.

Supposing x to be the Station, whose position is required to be determined, designate as follows the angles observed thereat:

$$\begin{aligned}x^{\circ} &= \angle \text{ between } A \text{ and } B \\x' &= \angle \text{ between } A \text{ and } C \\x'' &= \angle \text{ between } B \text{ and } C\end{aligned}$$

Now Station x may be either within the given triangle or without it. In the former case, $x^{\circ} + x' + x'' = 2\pi$ and in the latter $x' + x'' = x^{\circ}$. The first of these cases is represented by figure 1, and the latter by figures 2 and 3.

With regard to figures 2 and 3, it will be seen, that the difference between them consists in the line AB being placed in the former case between Stations C and x and in the latter on one side thereof. This circumstance should be borne in mind, as the general formula whereby diagrams 1 and 2 are solved, will require a slight modification when applied to diagram 3.

When a particular case of the problem under consideration is offered for solution, the Surveyor will draw a sketch thereof and compare it with diagrams 1 and 2 and 3. The sketch must agree with one of the diagrams. Holding the sketch in the same way as the diagram corresponding thereto is drawn in the book, the Surveyor will designate the several distances and angles in the sketch by those symbols, which are employed to denote similar elements in the diagram in question. This being done and calling A' the angle at Station A between C and x it will be found that—

$$\text{Cot } A' = - \frac{b \cdot \sin x''}{a \cdot \sin x' \sin (C + x' + x'')} - \cot (C + x' + x'')$$

In computing by this formula it will be remembered that $\angle C$ must be used as it stands for diagrams 1 and 2. But for

diagram 3, its complement to 360° will require to be employed in place of the original $\angle C$.

After due regard to the preceding rule, compute the two terms composing the value of cotangent A' and take out the result in natural numbers carried to 7 decimals. The signs of the natural numbers will be known on reference to the following table, the argument whereof is the numerical value of $(C + x' + x'')$.

Table exhibiting the signs of $\frac{b \sin x''}{a \sin x' \sin (C + x' + x'')}$ and $\cot. (C + x' + x'')$.

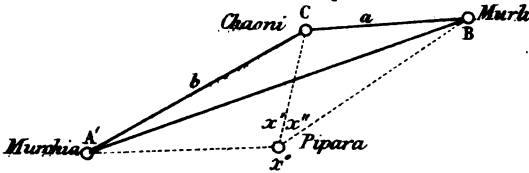
Values of $(C + x' + x'')$	Signs of	
	$\frac{b \sin x''}{a \sin x' \sin (C + x' + x'')}$	$\cot. (C + x' + x'')$
1st Quadrant,	—	—
2nd Quadrant,	—	+
3rd Quadrant,	+	—
4th Quadrant,	+	+

After affixing proper signs to the natural numbers, add them together, the sum is the natural cotangent of A' : or when a table of natural cotangents is not at hand, the logarithm of the sum may be taken, which is the logarithmic cotangent of A' , the logarithm being taken without reference to the sign of the sum, which may be either positive or negative.

When the sum is positive, the tabular arc corresponding to the computed cotangent is the value of A' ; when it is negative, the supplement to the tabular arc is the required value of A' . $\angle A'$ being determined, the other angles of the triangles formed by the point sought and the three known Stations may be easily deduced by the simple operations of addition and subtraction.

EXAMPLE.

Murchia, Chaoni and Murli being observed from Pipara, it is required to compute the position of the last mentioned point.



Elements given.

Side Chaoni to Murli,	a	Log.	4.4766465
Side Chaoni to Murchia,	b	Log.	4.7187414
∠ Chaoni, between Murli and Murchia, .. C	.....		158° 38' 38"

Observed Angles at Pipara.

Between Murli and Murchia,	x''	=	150 18 24
Between Murchia and Chaoni,	x'	=	107 29 10
Between Chaoni and Murli,	x'	=	42 49 14

Elements sought.

∠ Murchia between Pipara and Chaoni or A'

Type of Calculation.

	1st Term.	2nd Term.
$C = 158^\circ 38' 38''$		
$x' = 107 29 10$ Cosec.	0.0205473	
$x'' = 42 49 14$ Sin.	9.8323201	
$C + x' + x'' = 308 57 2$ Cosec.	0.1091942	
b Log.	4.7187414	
a A. C. of Log.	5.5233535	
	<u>0.2041565</u>	- Cot. 9.9076028
	+ 1.6001344	+ 0.8083564
	+ 0.8083564	
Cot. A' = + 2.4084908	Log. 0.3817450	
		A' = 22° 32' 54"

In carrying on a Detail Survey, it sometimes happens that the Theodolite cannot be planted over the centre of a Station. When this is the case, the instrument may be placed on one side of it, and angles taken to the surrounding signals. It is clear that these angles before they can be employed in the computation of the triangulation, will require to be transferred

Reduction of angles to the centre of a Station.

to the centre of Station, the geometrical construction for which problem was given at page 87. This reduction may be easily effected in the following manner.

Of the two points (A and B) observed from a Station C that may be called the right hand point, the reading of which in the deduction of an angle, is used as the subtrahend; the other point, whose reading is employed as the subtractor in the same operation, being styled the left hand point.

Considering the reading of the true centre as $0^{\circ} 0' 0''$, observe or compute as may be necessary from the centre of observation, the readings of Stations A and B . Call these readings A' and B' .

Likewise let α and β represent the distances of Station C to Stations A and B respectively: which distances are obtained from an approximate computation of $\triangle ABC$ by using the angles as they are derived from observation unaltered by any correction.

And lastly, let ϵ designate the distance derived from measurement of true centre from centre of observation.

Now compute the two following terms, and prefix thereto the signs given in the table subjoined.

$$\delta A = \frac{\epsilon \sin A' \operatorname{cosec} 1''}{\alpha} \qquad \delta B = \frac{\epsilon \sin B' \operatorname{cosec} 1''}{\beta}$$

The numerical values of these terms will be in seconds, the sum whereof is the correction required to the observed angle between A and B .

Table exhibiting the signs of the foregoing corrections.

Reading of Station A . by considering the reading of the true centre as $0^{\circ} 0' 0''$.	Signs of corrections for Station A .	
	When Station A is left hand point.	When Station A is right hand point.
1st Quadrant,	—	+
2nd Quadrant,	—	+
3rd Quadrant,	+	—
4th Quadrant,	+	—

EXAMPLE.

At the secondary Station of Manda of the Gurwani Meridional Series, the Theodolite in one instance was not placed over the Station centre, but at the distance of 11.67 feet from it, on which occasion the angle taken was that between the Station *C'* and Baraganj Temple, the correction to which for excentricity may be deduced as follows :—

To compute the correction for Station C', left hand point.

From centre of observation, Reading of Station <i>C'</i> by considering $0^{\circ} 0' 0''$ as the reading of true centre,	128° 4' 20" Sin	9.89610
Distance from centre of observation to true centre,	11.67 feet Log.	1.06707
Approximate distance from Manda to Station <i>C'</i> in feet,	A. C. of Log.	5.42404
Cosec $1''$	Constant Log.	5.31443
1st part of correction,	— $50''.3$	Log. <u>1.70164</u>

To compute the correction for Baraganj Temple, right hand point.

From centre of observation reading of Baraganj Temple by assuming true centre to read $0^{\circ} 0' 0''$, }	195° 14' 40" Sin	9.41985
Distance from centre of observation to true centre,	11.67 feet Log.	1.06707
Approximate distance from Manda to Baraganj Temple in feet,	A. C. of Log.	6.05584
Cosec $1''$	Constant Log.	5.31443
2nd part of correction,	— $72''.0$	Log. <u>1.85719</u>

Hence the total correction is — $50''.3 - 72''.0$	= $-0^{\circ} 2' 2''$
Observed Angle, ..	= <u>67 10 20</u>
Corrected Angle,	= <u>67 8 18</u>

CHAPTER XXII.

ON BAROMETRICAL HEIGHTS.

To determine barometrically the difference of height between two places, the implements required are two Barometers with their attached Thermometers and two detached common air Thermometers. Before giving the formula and rules however for this process, it is necessary to say a few words on the construction and method of using the Mercurial Barometer, a description of which instrument has been inadvertently omitted in Part 2. We have therefore given in the foot notes, some useful remarks lately published in a small Manual by Mr. Belville of the Royal Observatory, Greenwich.*

The Barometers which are commonly made use of in the measurement of a height are *Mountain* Barometers, so called from their extreme portability, being constructed so that the tripod stand, when closed, serves as a safe and convenient packing case. They can be opened, observed, and packed up again in the space of about ten minutes. The Mountain Barometer is capable of being used extensively by one individual, and the observations, if performed with care, will give results very near the truth. The instrument is not liable to injury in travelling, if proper precautions are taken, the most essential of

* *On the Construction and Method of Using the Mercurial Barometer.*

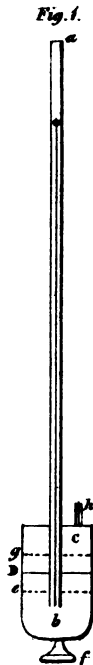
There are various forms of the Barometer, but the one best suited for meteorological observations consists of a tube about 33 inches in length, the extremity of which is inserted into a small reservoir or cistern ; and in order

which is always to carry *the cistern inverted*, and, when in this position, to turn the screws at the bottom of the cistern until the mercury *almost* touches the top of the tube and thereby prevent the oscillations from breaking it. Newman's instruments differ in their construction from the Englefield Barometer in the adoption of a double iron cistern with a solid bottom in lieu of the wooden cistern and leather bag. In the old instrument the screw at the bottom compresses the

to maintain the mercury in the cistern always at the same level, the cistern is constructed partly of leather, that by means of a screw at the bottom, the surface of the mercury in it may be so adjusted, as to have it always at the place from which the scale commences. Some Barometers are furnished with a gauge or float, that in great elevations and depressions the observer may perceive when the mercury in the cistern sinks too low or rises too high.

Let *a b*, fig. 1, be the glass tube plunged into the mercury in the cistern *C*, and *D* the surface-line of the fluid in the cistern level with the commencement of the scale, and adjusted to the particular height of the mercury in the tube, which has been actually measured from the surface of the cistern, in the construction of the instrument (which height is called its neutral point) : when the mercury rises in the tube, a portion, equal to that rise, leaves the cistern, and the surface-line falls towards the dotted line *e*; and being lower than the surface from which its neutral point was measured, the actual variation in the atmosphere is indicated too little : turn the screw *f* until the lines on the float *h* coincide, and the mercury then records the exact change : when depressions occur, the mercury sinking from the tube into the cistern raises the surface-line towards *g* : in this case the screw *f* must be unscrewed until the leather at the bottom of the cistern be sufficiently loosened to allow the mercury to assume its proper level at the surface *D*.

When there is not a gauge to the Barometer, the relative capacities of the cistern and tube are ascertained by experiment, in the construction of the instrument, and marked thereon ; as is also its neutral point. In this case, when the mercury in the tube is above the neutral point, the difference between it and the neutral point is to be divided by the *capacity*, and the quotient *added* to the observed height will give the correct height ; if the mercury be below the neutral point, the difference is to be *divided* as before, and the quotient *subtracted* from the observed height will give the correct height.



whole of the mercury in the cistern as well as in the tube, frequently forcing it through the pores of the wood, thereby rendering the Barometer useless; this defect has now been remedied, and the mercury secured for travelling, or set at

Let capacity for every inch of elevation of the mercury in the tube be equal to $\frac{1}{10}$, which, reduced to a decimal, will be

In.	In.	In.
=0.025 for one inch,	0.013 for $\frac{1}{2}$ inch,	0.007 for $\frac{1}{4}$ in.
Observed height	Inches, =30.400	Observed height
Neutral point.....	=30.000	Neutral point.....
Difference above neutral } point .....	.400	Difference below neutral } point.....
Add for capacity	+ .010	Subtract for capacity
Correct height	30.410	Correct height
		29.487

The scale of the Standard Barometer used in fixed observatories is made movable, and terminates in an ivory point, which is brought down to the surface of the mercury: when this point and its reflection appear to touch one another, the height indicated is correct. This kind of Barometer requires no adjustment or correction for the cistern.

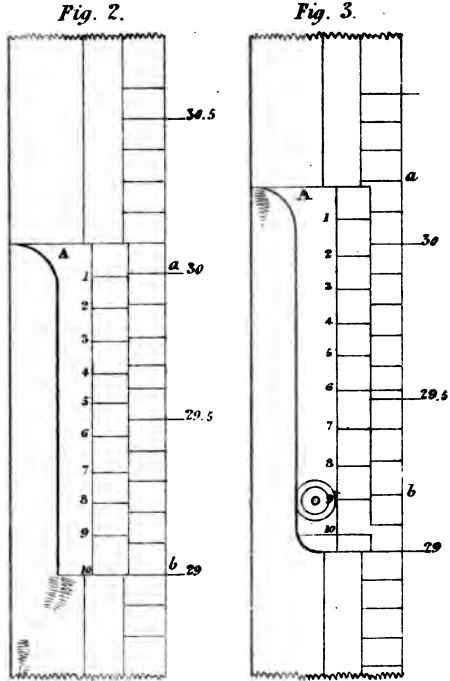
The tubes of Barometers vary in size: those of a large diameter are preferable, as the motion of the fluid is freer, and its friction against the sides of the tube is nearly inappreciable; tubes of small diameters require correction for capillarity, or the depression of the mercury caused by its adhesion to the sides of the tube.

The range of the Barometer, or the spaces passed through by the mercury in its extreme depressions and elevations, being limited to $3\frac{1}{2}$ inches, it is not usual to graduate the scale from the lower end of the tube: the divisions commence at 27 inches, and are continued to 31 inches. The graduations on Troughton's Mountain Barometers for measuring great elevations, commence at 15 inches and are carried on to 33 inches. Each inch is divided into ten equal parts, and these parts are subdivided into hundredths by means of a Vernier (so named from Peter Vernier, its inventor). The Vernier *A*, (figs. 2 & 3) is a movable plate, one inch and one-tenth of an inch (together equal to $\frac{11}{10}$) in length; these eleven-tenths are divided into ten equal parts, each part being equal to one-tenth of an inch and one-tenth of a tenth, together equal to eleven hundredths. When the pointer of the Vernier coincides with a division of the Barometer scale, as in fig. 2, each division of the Vernier will exceed each division of the scale respectively by 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 parts, whose denominators are the number of parts between *a*, *b*; the excess of each division being $\frac{1}{10}$ of a tenth or $\frac{1}{100}$, $\frac{2}{10}$ of a tenth or $\frac{2}{100}$, $\frac{3}{10}$ of a tenth or $\frac{3}{100}$, $\frac{4}{10}$ of a tenth or $\frac{4}{100}$, &c. The pointer in this position reads off

liberty for use, by holding the instrument with the cistern end upwards at an angle of about 45° , and moving the upper part from left to right, making the word "*portable*," engraved on

to inches and tenths, viz. thirty inches and one tenth, expressed in figures 30·10 inches.

When the *pointer* does not coincide with a division of the scale as in fig. 3, observe which division of the Vernier does coincide; and the number placed against that division of the Vernier will be the number of hundredths to be added to the inches and tenths. In fig. 3, 7 coincides with a division of the Barometer scale, and therefore 7 hundredths are to be added to the inches and tenths, and the reading is thirty inches, one tenth and seven hundredths, expressed in figures 30·17 inches. By an alteration in the divisions of the Vernier, the Mountain and Standard Barometer are read off to $\frac{1}{100}$ of an inch.



A Thermometer is attached to the Barometer to indicate the temperature of the mercury in the cistern; all bodies expand by heat and contract with cold; the expansion of mercury is easily tested by exposing a mercurial Thermometer to the heat of a fire, or by placing it in hot water: as the warmth increases, the mercury will expand and ascend in the tube; as it diminishes it will contract and fall towards the bulb: if the Thermometer be plunged into a mixture of pounded ice and common salt, from the intense cold produced by the conversion of the ice into water, the mercury will sink to zero, or 32° below the freezing-point of Fahrenheit; if the tube of the Thermometer should not be long enough to admit of so low a graduation, the mercury will shrink into the bulb. The expansion of mercury is $\frac{1}{1000}$ of its bulk for each degree of Fahrenheit between 32° and 212° . For convenience, tables have been computed, from which may be taken out, at sight, the amount

the cistern, coincide with the *stop*, or by a contrary motion bringing the words "*not portable*" opposite the *stop*, when the instrument is intended for use.

to be subtracted from the height of the mercurial column, on account of the expansion of the mercury from temperature.

The words Change, Fair, and Rain, engraved on the plate of the Barometer, were placed there by the first observers of its variations : no great importance should be attached to them ; for from the observations of two centuries we find, that heavy rains, and of long continuance, take place with the mercury at 29·5 inches, or Change ; that rain frequently falls when it stands as high as 30·00 inches, or Fair ; and more particularly in winter, a fine bright day will succeed a stormy night, the mercury ranging as low as 29·00 inches, or opposite to Rain. It is not so much the *absolute* height as the actual rising and falling of the mercury which determines the kind of weather likely to follow. The late great elevation of 30·9 inches in February of the present year 1849, (in England) was succeeded by a minimum of 29·25 inches, which produced a storm of wind so violent that the horizontal pressure of many of the gusts amounted to 20lbs. upon the square foot ; a pressure which is rarely exceeded, even when the Barometer falls as low as 28·25 inches. This may appear extraordinary if we merely take into consideration the actual height of the column, and neglect the *quantity* of the fall which amounted to 1·65 inch. The mean height of the greatest observed elevations for the last thirty-eight years is 30·61 inches, and the mean height of the observed depressions for the same period is 28·69 inches ; therefore a fall in the mercury of 1·65 inch from the mean of the elevations would give a *minimum* of 28·96 inches ; a depression which is contemporary with violent storms, as it is within three-tenths of the mean of the lowest depressions of the Barometer.

In fixing the Barometer great care must be taken to place it perpendicular : a situation should be selected subject to the least change of temperature, for which reason a northern aspect is preferable to a southern ; the height of the cistern of the Barometer above the level of the sea, and, if possible, the difference of the height of the mercury with some standard, should be ascertained, in order that the observations made with it should be comparative with others made in different parts of the country. Before taking an observation, the instrument should be gently tapped to prevent any adhesion of the mercury to the tube, the gauge should be adjusted to the surface-line of the cistern, and the index of the Vernier brought level with the top of the mercury. If the Barometer have a Vernier which admits the light from behind, the lower part of the pointer must make a tangent with the convex part of the mercury in the tube. In reading off the observation the eye should be on a line with the mercury ; as by placing it above, the reading would be too low, and by placing it below, it would be too high. This difference in the manner of reading

This instrument also varies from the common Barometer, being a *standard* in itself, the actual distance between the height of the mercury in the tube, and the level in the cistern having been measured without reference to any other Barometer. In such instruments where the cistern is entirely enclosed from view, an allowance must be made to reduce the reading on the scale to what it would have been if the mercury in the cistern had been adjusted to zero. It is evident that this correction of the height of the column of mercury must be proportioned to the relative capacities of the cistern and the bore of the tube. Thus supposing the interior diameter of the tube to be $\cdot 1$ its exterior $\cdot 3$, and the diameter of the cistern $\cdot 9$ inches, the ratio of the areas of the surfaces will be $(81-9)$ or 72 to 1. The difference then between the observed reading of the Barometer and that of the "*neutral point*," which is the height at which the mercury stood in the

off is called error from parallax. It is indispensable that a reading of the attached Thermometer be made simultaneously with the observation of the height of the mercury. Accuracy is the spirit of observation. A careful reading of inches, tenths and hundredths produces excellent results: the $\frac{10}{1000}$ place is better left to the skill of the old observer who is usually obliged to estimate it, scarcely any Barometer being graduated with sufficient precision to trust to the divisions for so small a quantity.

The Barometer is slightly affected periodically during the twenty-four hours: at 9 A.M. and 9 P.M. it stands higher, and at 3 A.M. and 3 P.M. it stands lower; the mean annual difference amounts nearly to $\cdot 03$ of an inch. These four periods of the day have been recommended for observation by the Committee of Physics of the Royal Society. It is usual, for the sake of comparison, to reduce the observations to 32° of Fahrenheit.

In.

Ex. If barom. stood at 29.900 therm. attached 54° ,
Correct for temp. $-.057$ (by table),

Height of barom. at	}	29.843
temp. of 32°		

The Wheel-barometer, from its construction, cannot be trusted to for correct heights; it merely shows if the mercury be in a rising or falling state: it may rather be considered as an ornamental piece of furniture than as having the slightest pretensions to a scientific instrument.

tube above the zero mark of the cistern when the instrument was first made (which is always marked *N. P.*) is to be diminished in this proportion, and the quotient applied to the observed reading, *additive* when it is above this standard, and *subtractive* when below. The small correction for the capillary attraction of the glass tube, the effect of which is constantly to depress the mercury in the tube by a certain quantity, is constant and additive, and is generally allowed for by the maker in laying off the neutral point, in which case no further notice need be taken of it.

- a. Cistern of Iron.
- b. Thermometer immersed in cistern.
- c. Milled screw for moving scale *e* up or down.
- d. Vernier, being a fixture.
- e. Scale divided into inches, 10ths and 100ths. The scale reads down to 20 inches.
- f. Index arrow to bisect the surface of mercury in the tube.
- g. Suspension ring.

At the back of the scale *e* the *neutral point, capillary-action, and capacities* are engraved. To render the instrument *portable, or not portable*, the lower part of the cistern or from the bottom moulding to the centre, is capable of being turned half round, and an arrow indicates when the cistern closes the mercury, so as to prevent its returning into the cistern which then points to the word *portable* engraved on the cistern, the opposite direction allows the mercury to return, and the instrument then becomes *not portable* but serviceable.

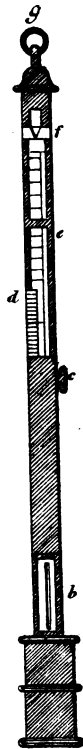


Fig. 2.



Fig. 1.

The Barometer of Troughton's or Jones' pattern, Fig. 1, is attached to the stand by a ring in which it turns round with a smooth and steady motion, for the purpose of placing it in the best light for reading off, &c.; but in Newman's more modern instruments, Fig. 2, the tubes are enclosed in a bronzed metal case with a simple ring at the top by which it may be suspended from any fixed and steady projection in a perpendicular position, thus obviating the necessity for a tripod stand. This instrument is merely enclosed in a strong leather case, and may be strapped across the back, in the position above described; but portable as Newman's instruments are, and perfectly secured as they seem to be, still the greatest caution must be employed in carrying them, especially by explorers and travellers in this country, where a fresh tube, it must be remembered, is not readily supplied and properly filled.

It is of course preferable to have two Barometers and to make simultaneous observations, as during changeable weather, dependance cannot be placed upon results with only one; particularly if *any considerable interval of time* has elapsed between the comparison of the heights of the mercury at the different stations. Even the method of noting the time of each observation, ending the day's work at the spot where it was commenced, and then correcting the readings of the Barometer and Thermometer at each Station, for the proportion of the total change between the first and last reading due to the respective intervals of time, cannot of course render observations taken with one Barometer equal in accuracy to those observed simultaneously with two instruments, unless the rise or fall of the Barometer, and particularly of the Thermometer, was ascertained to have been *uniformly progressive* during the whole day. Observing however the Barometer again at the first station at close of the day has this advantage, that any great change during the period will be immediately detected, and the degree of dependance to be placed on the observation made evident.

The difference of readings owing to these changes will also be generally subdivided among a number of observations though instances *may* occur where this caution, *as regards the Thermometer*, will be productive of error in the result.

In exploratory expeditions into distant countries where it is obviously impracticable to make simultaneous observations at the different elevations as they are met with in the course of each day's journey, the comparisons must be instituted with the observations taken at any fixed observatory, and which are generally published for general information, or at any known station the height of which has been *previously determined*. To effect this, the traveller's instrument must of course, in the first instance, be duly compared with the standard in the observatory, the height of which above the sea level is known; or with the instrument left at any particular Station, where the hours for observation have been previously mutually agreed on.

The two Barometers selected for the measurement of heights, having been compared with each other, the difference, if any, existing between them will be determined. The whole of this difference called the *Index Error* being applied as a correction to one or the other Barometer, their readings will obviously become equalized.

Under ordinary circumstances probably ten comparisons at intervals of a few minutes from each other, after at least half an hour's quiet exposure of both instruments side by side would be sufficient for the correct determination of the Index error abovementioned, but in cases where the Barometers do not maintain a constant difference, twenty, thirty, or even forty comparisons may be taken with advantage. Previous to every trial, the Barometers ought to be thrown out of adjustment and then re-adjusted and observed. After every fourth or fifth comparison the Barometers should be reversed and put up again.

While the Barometer comparisons are going on, the attached and detached Thermometers may likewise be compared.

The mean difference between the two attached, as likewise that between the two detached Thermometers, being computed, they should be used in the same way as the mean difference between the two Barometers, viz., for equalizing their readings.

After these preliminary comparisons have been executed, the measurement of a height by barometrical observation may be taken in hand. For this purpose an observer with a Barometer, and a detached Thermometer being placed at the lower Station, and another observer with similar instruments being posted at the upper, let them observe simultaneously, that is to say, at certain times previously fixed upon, continuing the observations for as many days as may be convenient. If the weather during the observations be clear and steady, then the difference of height derived from this measurement would be worthy of great confidence.

For the deduction of a height from barometrical observations the formula commonly made use of, is that given by La Place. It takes into account the indications of the Barometer and Thermometer, but not those of the Hygrometer. Perhaps this omission is a defect of La Place's process of computation. Professor Bessel has investigated a formula in which the three conditions abovementioned have been made use of. We are not aware that this formula has been tested by a sufficient number of experiments to warrant its introduction into this work.

In computing by La Place's formula, the symbols used for designating observed elements are as follows:—

OBSERVED ELEMENTS.	STATIONS.	
	Upper.	Lower.
Height of Thermometer in open air,	t'	t
„ Thermometer attached,	T'	T
„ Barometer,	β'	β

This being premised; it will not be difficult to explain the process of computation. The barometrical columnus β and β' represent atmospheric pressure at the two given Stations, and as the lengths of these columns vary with the temperature (T and T') of the mercury, it is clear that before they can be used as elements of computation, they will require reduction to one common temperature. Again, the atmosphere itself as regards density, does not remain in one invariable mean state; it is undergoing continual changes, produced by the greater or smaller amount of heat existing therein, and indicated by t and t' . This being the case, it is clear that the correction for temperature must form an important part of the deduction of the difference of height from the difference of atmospheric pressure at two given places. And lastly, the force of gravity should likewise be taken into account, which under a given latitude, varying with the height ascended, must, though in a small degree, influence and modify atmospheric pressure at different elevations.

These are the general considerations upon which La Place's formula for the deduction of height is based, and in order that the corrections which they give rise to, may be of easy computation, Tables *A*, *B*, *C* are subjoined. It will be seen that *A*, furnishes the correction for the temperature of the atmosphere, *B*, for that of the mercury, and *C*, for that of gravity under any latitude λ .

We will explain the use of one of these Tables, *A* for instance, as that explanation will serve for the others. Enter this Table with the numerical value of $(t+t')$. If that value is forthcoming in the Table, then the quantity opposite is the proper value of *A*.

Table for determining Altitudes with the Mountain Barometer.

Thermometers in Open Air.							
$t+t'$	A.	$t+t'$	A.	$t+t'$	A.	$t+t'$	A.
40	4.76891	80	4.78830	120	4.80686	160	4.82466
41	4.76940	81	4.78877	121	4.80731	161	4.82509
42	4.76990	82	4.78924	122	4.80777	162	4.82553
43	4.77039	83	4.78972	123	4.80822	163	4.82596
44	4.77089	84	4.79019	124	4.80867	164	4.82640
45	4.77138	85	4.79066	125	4.80912	165	4.82683
46	4.77187	86	4.79113	126	4.80957	166	4.82727
47	4.77236	87	4.79160	127	4.81003	167	4.82770
48	4.77286	88	4.79207	128	4.81048	168	4.82813
49	4.77335	89	4.79254	129	4.81093	169	4.82856
50	4.77384	90	4.79301	130	4.81138	170	4.82900
51	4.77433	91	4.79348	131	4.81183	171	4.82943
52	4.77482	92	4.79395	132	4.81227	172	4.82986
53	4.77530	93	4.79442	133	4.81272	173	4.83029
54	4.77579	94	4.79488	134	4.81317	174	4.83072
55	4.77628	95	4.79535	135	4.81362	175	4.83115
56	4.77677	96	4.79582	136	4.81407	176	4.83158
57	4.77725	97	4.79628	137	4.81451	177	4.83201
58	4.77774	98	4.79675	138	4.81496	178	4.83244
59	4.77823	99	4.79721	139	4.81540	179	4.83286
60	4.77871	100	4.79768	140	4.81585	180	4.83329
61	4.77920	101	4.79814	141	4.81629	181	4.83372
62	4.77968	102	4.79860	142	4.81674	182	4.83415
63	4.78016	103	4.79907	143	4.81718	183	4.83457
64	4.78065	104	4.79953	144	4.81763	184	4.83500
65	4.78113	105	4.79999	145	4.81807	185	4.83542
66	4.78161	106	4.80045	146	4.81851	186	4.83585
67	4.78209	107	4.80091	147	4.81895	187	4.83627
68	4.78257	108	4.80137	148	4.81939	188	4.83670
69	4.78305	109	4.80183	149	4.81984	189	4.83712
70	4.78353	110	4.80229	150	4.82028	190	4.83754
71	4.78401	111	4.80275	151	4.82072	191	4.83797
72	4.78449	112	4.80321	152	4.82116	192	4.83839
73	4.78497	113	4.80367	153	4.82160	193	4.83881
74	4.78544	114	4.80412	154	4.82203	194	4.83923
75	4.78592	115	4.80458	155	4.82247	195	4.83966
76	4.78640	116	4.80504	156	4.82291	196	4.84008
77	4.78687	117	4.80549	157	4.82335	197	4.84050
78	4.78735	118	4.80595	158	4.82378	198	4.84092
79	4.78782	119	4.80640	159	4.82422	199	4.84134
80	4.78830	120	4.80686	160	4.82466	200	4.84176

Attached Thermometers.				Latitude of the place.			
$T - T'$	$B.$	$T - T'$	$B.$	λ	$C.$	λ	$C.$
0	0·00000	20	0·00087	8	0·00112	24	0·00078
1	0·00004	21	0·00091	9	0·00111	25	0·00075
2	0·00009	22	0·00096	10	0·00110	26	0·00072
3	0·00013	23	0·00100	11	0·00108	27	0·00069
4	0·00017	24	0·00104	12	0·00107	28	0·00065
5	0·00022	25	0·00109	13	0·00105	29	0·00062
6	0·00026	26	0·00113	14	0·00103	30	0·00059
7	0·00030	27	0·00117	15	0·00100	31	0·00055
8	0·00035	28	0·00122	16	0·00099	32	0·00051
9	0·00039	29	0·00126	17	0·00097	33	0·00048
10	0·00043	30	0·00130	18	0·00095	34	0·00044
11	0·00048	31	0·00134	19	0·00092	35	0·00040
12	0·00052	32	0·00139	20	0·00090	36	0·00036
13	0·00056	33	0·00143	21	0·00087	37	0·00032
14	0·00061	34	0·00147	22	0·00084	38	0·00028
15	0·00065	35	0·00152	23	0·00081	39	0·00024
16	0·00069	36	0·00156	24	0·00078	40	0·00020
17	0·00074	37	0·00160				
18	0·00078	38	0·00165				
19	0·00083	39	0·00169				
20	0·00087	40	0·00173				

If it be not forthcoming then take out A for $(t+t')$ next less, and correct it in this way:—Compute the difference between the Tabular quantities next less and next greater than the required value. Multiply this difference by the excess of the given argument above the Tabular argument next less; the product is the correction required, which is positive because the Tabular quantity A , forms an increasing series. In a similar manner, quantities B and C may be computed.

Calculating B , A , and C , from the Tables given above, and taking out the Logarithms of β and β' from a common Table

of Logarithms, the computation of the difference of height may be effected in the following manner:

$$\text{Put } D = \text{Log. } \beta - (\text{Log. } \beta' + B)$$

$$\text{Hence Log. } x = \text{Log. } D + A + C.$$

x being the difference of altitude in feet, between the two Stations.

Deduction of the Height of Sonakoda G. T. Station above Calcutta Observatory, by using the six simultaneous Barometrical observations made at both places on the 6th December, 1847.

Mean Latitude, = 24° 24'		(Table column C.) 0·00077
Upper Station, Sonakoda,		Lower Station, Calcutta Observatory.
Upper.		Lower.
Thermometer in open air, ... $t' = 70\cdot8$		$t = 72\cdot8$
Thermometer attached, ... $T' = 70\cdot8$		$T = 73\cdot2$
Barometer, $\beta' = 29\cdot957$		$\beta = 30\cdot169$
$(T - T') = 2\cdot4$ (Table, column B.) 0·00011 ; $(t - t') = 143\cdot6$ (Table, column A.) 4·81745		
$\therefore B = 0\cdot00011$		Log. = 5·46982
Log. $\beta = 1\cdot47650$		from column C = 0·00077
Log. $\beta' + B = 1\cdot47661$		from column A = 4·81745
Log. β ... = 1·47956		<u>2·28804</u>
Difference = 0·00295	Log.	Difference of height = 194·1 feet.

The Barometers used at Sonakoda were those marked Nos. 2 and 3 by Troughton and Simms, of which the mean is taken as the numerical value for β' . The standard Barometer

No. 86, by Newman was observed at the Calcutta Observatory.

By 6 corresponding barometrical observations on the 6th December 1847, the mean height of the cisterns of Barometers Nos. 2 and 3, above the cistern of the Calcutta Barometer as deduced above is	Feet. 194·1
By 6 similar observations on the 7th December, ..	192·1
Ditto ditto 8th ditto,	194·7
Mean,	193·6
The cisterns of Nos. 2 and 3 above the station mark,	—2·0
Ditto of Calcutta Barometer above sea level,	+18·2
Height of Sonakoda Station above sea level barometrically,	209·8
The same deduced geodetically,	213·8
Discrepancy,	4·0

The deduction of this height of the Sonakoda Base in the Purneah district at a distance of 255 miles from Calcutta, agrees, as will be perceived, remarkably well with the Trigonometrical Calculation, the difference being only 4 feet. This proves the advantage of the systematic record of meteorological observations at a fixed observatory. The scientific researches of an officer lately employed in Kumaon tend to prove that his barometrical observations even across the Himalaya, follow all the Calcutta movements—and this view of the subject is confirmed by the deductions of the heights of the several mountains in Sikhim and Eastern Nepal by the accomplished traveller, lately traversing those parts, by means of similar simultaneous data, which have approximated in a remarkable manner to the trigonometrical results obtained by the Surveyor General of India. This adds therefore a peculiar value to the Calcutta Register and renders the observa-

tions there taken of great service to the traveller. The *day* curves given in this register are quite perfect, but it wants the 3 *a. m.* and 10 *p. m.* observations to make it complete as a meteorological record.

An example of the difference of elevation between the top of the monastery hill at Darjeeling, and Mr. Muller's house at the same place worked out by Bessel's and La Place's formulæ give the following results:

By Bessel,	214·20 Feet.
By La Place,	214·35
Difference,	0·15

and agreeing with the trigonometrical height by 0·9 feet. The difference therefore, caused by the hygrometric state of the atmosphere, and allowed for by Bessel, but not taken into account by La Place, does not appear to be worthy of notice.

A set of most useful "Tables for determining the altitudes of mountains by the Barometer and boiling point Thermometer," have lately been published by Lieut. Colonel J. T. Boileau, the Superintendent of the Simlah Magnetic Observatory,* and no traveller should go without them. The *barometrical* Tables computed from Oltmann's formulæ, are particularly convenient, especially for persons who are not accustomed to logarithms. "The comparisons of English and French measures and of the different Thermometers" are also frequently required for reference in a country where you cannot always choose your own instruments, or foresee whether a Centigrade, Reaumur, or Fahrenheit Thermometer is to be used. The *thermometrical* Tables for finding the heights of the Barometer corresponding to different boiling points, have been computed from Regnault's Table of the Elastic Forces of aqueous vapour, published in Taylor's Scientific Memoirs,

* Printed at the Magnetic Observatory Press, Meerut, July 1849.

volume 4th, to every tenth of a degree of Fahrenheit. The whole of these Tables are too elaborate, for any thing beyond a passing remark in this work, but we may safely recommend the compilation to general notice, and express a hope that the intention hinted at in the Preface “of a reprint with additions,” may be speedily carried out. We must therefore content ourselves with giving a general explanation of this latter mode of proceeding for the determination of heights.

THERMOMETRICALLY.

Those only, who have had any practical experience with such delicate and expensive instruments, as Mercurial Mountain Barometers, can be fully aware of the disappointments met with in a country like this, where the dangers and difficulties experienced with instruments of this description, are so constant, and the means of transit so unsuited to their use, and for replacing them from such great distances, any substitute, therefore, by which the heights of places may be measured, cannot fail to be extremely useful in many instances and situations, which are perpetually occurring with travellers and explorers in the countries bordering on the British possessions in India. The *common Thermometer* has been frequently practised in India for determining heights by the different temperatures of *boiling water*. According as the atmospheric pressure diminishes, so does water boil at lower temperatures, and thus the boiling point of water at different heights is computed to measure these heights. The Thermometer used

ON THE USE OF COMMON THERMOMETERS TO DETERMINE HEIGHTS.

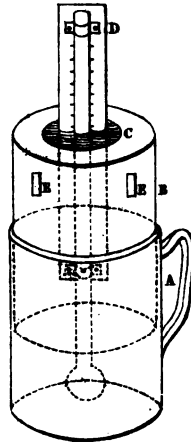
Having been recently applied to by two gentlemen about to travel—the one in Africa and the other in Asia Minor—for a description of the Thermometers and apparatus used by myself for some years in India for determining heights by the boiling temperature of water, I have ventured to believe that a brief ac-

for this particular purpose, is described by Lieut. Colonel W. H. Sykes, F. R. S., in the 8th volume of the London Geographical Journal, wherein he has also given the Tables deduced by the late James Prinsep, to facilitate the computation of altitudes, as well as examples, for their practical application. These we have given in the foot notes, rendering but little further explanation necessary. The instrument with boiling apparatus

count of a process which I found to produce results sufficiently near to the truth for most practical purposes, may not be unacceptable to some members of the Society, particularly as I carried on my barometrical observations contemporaneously, and thereby obtained data for fixing the value of certain points on the thermometric scale. To determine heights accurately, good Barometers are necessary, which have been carefully compared with a standard Barometer: the observations must be taken simultaneously at the upper and lower stations, and the temperature of the mercury and the air, and the hygrometric state of the latter, must be noted. Heights so determined, when tested again in the same or succeeding years, I have rarely found to vary more than 10 or 20 feet in 4000 or 5000. When Barometers are used which have not been previously compared with a standard, when the observations are not simultaneous, and when the pressure and temperature at the level of the sea are *assumed*, the results may, by accident, be near to the truth, but they will usually be from 100 to 300 feet wrong,—at least such is the result of my experience within the Tropics. But good Barometers are very costly; they are troublesome to carry, are particularly exposed to accident on a journey, and get out of order by the escape of the mercury, which being frequently unobserved, the Barometer continues to be used as if it were correct. The late Archdeacon Wollaston, aware of these facts, invented the thermometric Barometer to supply the place of the ordinary Barometer. This instrument is very sensible, but it is very fragile from the great weight of the bulb compared with the slenderness of the stem; moreover, there are some complex accompaniments, and the instrument is also expensive: in short, I found it not fit for *rough work* out-of-doors, having had three destroyed at the outset of my labours; and the same opinion is expressed by Mr. James Prinsep, of Calcutta, who is well known for the practical application of his scientific knowledge. I had then recourse to common Thermometers, and, with certain precautions in their use, found them answer my purpose sufficiently well. A tin shaving-pot was my boiler; dry sticks and pure water were usually to be had, and by the time my Barometers were settled, I was ready to take the boiling temperature. The following is a sketch of the apparatus.

complete is extremely simple, and any Thermometer with metal scale, reading sufficiently high, may be adapted to the *shaving pot* as described by Colonel Sykes. The great portability, and less liability to injury over the Barometer is the chief

It will be seen that the chief part of the scale usually attached to the Thermometer is removed, only so much of it being left as may be desirable : I, however, permitted the brass scale of one of my Thermometers to remain, and I did not discover that it was the cause of error. Previously to taking the Thermometers inland, it is necessary to ascertain their boiling points at the level of the sea ; for in many instances the scales are so carelessly applied, that a Thermometer may indicate a boiling temperature of 213° , 214° , or 215° at the level of the sea ; one of mine stood at 214.2 when water boiled. Nevertheless, by making a deduction of $2^{\circ} 2'$ in all observation, the indications rarely differed five-hundredths of a degree from the other Thermometer, of which the boiling point was 212° : the temperature of the air and the height of the Barometer at the time the *verification* of the Thermometers is made must be noted. The following is the manner in which my observations were taken:—from 4 to 5 inches of *pure* water were put into the tin pot ; the Thermometer was fitted into the aperture in the lid of the sliding tube by means of a collar of cork ; the tin tube was then pushed up or down to admit of the bulb of the Thermometer, being about *two inches*, above the bottom of the pot. Violent ebullition was continued for 10 minutes or a quarter of an hour, and the height of the mercury was repeatedly ascertained during that time, and the temperature of the air was noticed. Similar operations were repeated with a *second* Thermometer, for it is never safe to rely upon *one* instrument. Having obtained the boiling points, it remains to determine the value of the indication of diminished pressure when the observations are taken above the level of the sea. The elastic tension of steam at different points on the thermometric scale has been determined by experiment, but not at regular intervals on the scale, nor



A. A common tin pot, 9 inches high by 2 in diameter.

B. A sliding tube of the moving up and down in the pot; the head of the tube is closed, but has a slit in it, C, to admit of the Thermometer passing through a collar of cork which shuts up the slit where the Thermometer is placed.

D. Thermometer, with so much of the scale left only as may be desirable.

E. Holes for the escape of steam.

recommendation of this instrument, for of course the same accuracy cannot be expected from it. The results deduced from the use of these Tables appear always *rather less* than those obtained from careful barometrical observations, and if

with similar results, by different persons : Tables, therefore, computed from the formulæ of the various experimenters, do not accord ; but, in three Tables which I have in my possession, the heights computed by them, when compared with heights determined by corresponding barometrical observations with previously compared Barometers (the only satisfactory way to ascertain heights not taken trigonometrically,) approximate sufficiently near for all practical purposes where great accuracy is not desired. These Tables, however, differ slightly from each other.

The Table which first came into my hands appeared anonymously in the *Madras Gazette* for 1824. In 1826, an able friend, Lieut. Robinson, of the Indian Navy, who entered warmly into my views to determine heights by common Thermometers, thought he could improve upon the Table I was using, and accordingly made a new computation : the third Table came under my notice much more recently than the two former. It is computed by Mr. James Prinsep, of Calcutta, Secretary of the Asiatic Society of Bengal, a gentleman distinguished for his scientific research. He published it in the *Journal of the Society*. To admit of a just estimate being formed of the value of these Tables,—of the value of corresponding barometrical observations, made with due precautions, although with different coadjutors and different instruments,—of the value of barometrical observations, with an assumed pressure and temperature, at the level of the sea,—of the value of thermometrical compared with barometrical observations,—out of many hundred heights determined in various ways, I have taken many at random (the number, it appears, is eighty-eight) and I have put them into juxtaposition in a Tabular form. In thermometric heights, the elements at the level of the sea were a boiling temperature of 212° Fahr. and a mean temperature of the air of 82°. The *assumed* pressure in heights determined barometrically, without corresponding observations, was 30 inches ; mean temperature 82°. In looking over the tabulated results, I was a good deal surprised to find that in no instance, by whatever method determined, do the barometric differences in height exceed 127 feet, and this only by comparing the highest indications with an assumed pressure with the lowest indications of corresponding observations. It will be seen that the various Tables for determining heights thermometrically, with certain exceptions, do not differ very *materially* in their results from each other, nor from corresponding barometric observations ; the formulæ on which they are founded may therefore be considered, on the whole, sufficiently accurate for the present state of our knowledge.

a number of careful observations obtained by both methods are compared together, or with a trigonometrical or levelling process, they will afford the means of making any necessary

Lieut. Robinson and Mr. Prinsep's Tables give close approximations to each other in their results, but they are so much below the corresponding barometric observations, which I consider the true heights, as the results by the Madras Table are above the true heights. Some of them curiously coincide within a foot or two of the heights determined by corresponding barometrical observations, but this coincidence must be the result of mere accident. Taking the mean of all the thermometric observations at a station calculated by the three Tables, and the mean of all the corresponding barometric observations at the same place, the utmost difference is 107 feet in less than 600; and the least difference is 8 feet in about 3000; but as the thermometric heights, in which the difference of 107 feet occurs, were single observations, made by a gentleman who had newly begun to use his Thermometers, they may be looked upon as probably less accurate than subsequent trials would have made them. This is scarcely an unjust inference, as it will be seen that the next greatest difference made by the same gentleman was only 24 feet in 4490. It must be admitted, however, that this amount of error is just as likely to occur in heights of 100 feet as in those of 10,000. My Thermometers were not graduated to less than half-degrees, and long practice enabled me to determine the height of the mercury in the steam to one-twentieth of a degree; but I would recommend Thermometers being used in which the degrees are graduated to fifths or tenths of a degree. On the whole, I think the results of six years' experience justify me in saying that common Thermometers may be satisfactorily used to supply the place of Barometers in measuring heights where great accuracy is not required; and it will be recollected that what is usually looked upon as a difficult and troublesome operation with Barometers, will be attainable by any person who carries with him a couple of Thermometers, the requisite tin pot, and the Tables, and who is master of the simplest rules of arithmetic.

Of the three Tables in my possession, I have chosen Mr. Prinsep's from their perspicuity and the facilities they offer for the conversion of boiling temperatures into heights with very little trouble; but a glance over the figures in my Tables of Altitudes will show that the Tables are susceptible of considerable improvement, for with two exceptions, all the heights deduced from Mr. Prinsep and Lieut. Robinson's are much below those determined by simultaneous observations with good Barometers; and I join with Mr. Prinsep in expressing a hope that every traveller boiling his Thermometers will, at the same time, if he possess a Barometer, make a record of its indication, and thus render essential service to physics, by fixing so many points on the scale of the elastic tension of steam at different temperatures.

corrections in the Tables. The approximation, however, is sufficiently close in the examples given in Colonel Sykes' book, as to induce great confidence in the method, and espe-

TABLE. I.

To find the Barometric Pressure and Elevation corresponding to any observed Temperature of Boiling Water between 214° and 180°.

Boiling Point of Water.	Barometer modified from Tredgold's Formula.	Logarithmic Differences or Fathoms.	Total Altitude from 30°00 in. or the Level of the Sea.	Value of each Degree in Feet of Altitude.	Proportional Part for One-tenth of a Degree.
°			Feet.	Feet.	Feet.
214	31·19	00·84·3	—1013	—505	...
213	30·59	84·5	507	—507	...
212	30·00	84·9	0	+509	...
211	29·42	85·2	+509	511	51
210	28·85	85·5	1021	513	...
209	28·29	85·8	1534	515	...
208	27·73	86·2	2049	517	...
207	27·18	86·6	2566	519	52
206	26·64	87·1	3085	522	...
205	26·11	87·5	3607	524	...
204	25·59	87·8	4131	526	...
203	25·08	88·1	4657	528	...
202	24·58	88·5	5185	531	53
201	24·08	88·9	5716	533	...
200	23·59	89·3	6250	536	...
199	23·11	89·7	6786	538	...
198	22·64	90·1	7324	541	54
197	22·17	90·5	7864	543	...
196	21·71	91·0	8407	546	...
195	21·26	91·4	8953	548	...
194	20·82	91·8	9502	551	55
193	20·39	92·2	10053	553	...
192	19·96	92·6	10606	556	...
191	19·54	93·0	11161	558	...
190	19·13	93·4	11719	560	56
189	18·72	93·8	12280	563	...
188	18·32	94·2	12843	565	...
187	17·93	94·6	13408	569	57
186	17·54	95·0	13977	572	...
185	17·16	95·9	14548	575	58
184	16·79	96·4	15124	578	...
183	16·42	96·9	15702	581	...
182	16·06	97·4	16284	584	...
181	15·70	97·9	16868	587	...
180	15·35		17455		59

The Fourth Column gives the Heights in Feet.

cially for determining the *comparative* altitudes of places in a mountainous country.

The Tables being given in degrees of *Fahrenheit*, it will be necessary in case *Centigrade* Thermometers are used, to convert these indications into the corresponding ones of *Fahrenheit*, for which the formula is $F = \frac{9c}{5} + 32$ whenever the

TABLE II.

Table of Multipliers to correct the Approximate Height for the Temperature of the Air.

Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.	Temperature of the Air.	Multiplier.
°		°		°	
32	1.000	52	1.042	72	1.088
33	1.002	53	1.044	73	1.085
34	1.004	54	1.046	74	1.087
35	1.006	55	1.048	75	1.089
36	1.008	56	1.050	76	1.091
37	1.010	57	1.052	77	1.094
38	1.012	58	1.054	78	1.096
39	1.015	59	1.056	79	1.098
40	1.017	60	1.058	80	1.100
41	1.019	61	1.060	81	1.102
42	1.021	62	1.062	82	1.104
43	1.023	63	1.064	83	1.106
44	1.025	64	1.066	84	1.108
45	1.027	65	1.069	85	1.110
46	1.029	66	1.071	86	1.112
47	1.031	67	1.073	87	1.114
48	1.033	68	1.075	88	1.116
49	1.035	69	1.077	89	1.118
50	1.037	70	1.079	90	1.121
51	1.039	71	1.081	91	1.123

Enter with the mean temperature of the stratum of air traversed, and multiply the approximate height by the number opposite, for the true altitude.

degrees are above the freezing point of water, and *vice versá*, for converting Fahrenheit into Centigrade measure—the formula will be $C = \frac{(F-32) \times 5}{9}$

When the Thermometer has been boiled at the foot and at the summit of a mountain, nothing more is necessary than to deduct the number in the column of feet opposite the boiling point below from the same of the boiling point above: this gives an approximate height, to be multiplied by the number opposite the *mean* temperature of the air in Table II, for the correct altitude.

	°	feet.
Boiling point at summit of Hill Fort of Púrundhur, near Púna	204·2	= 4027
Boiling point at Hay Cottage, Púna	208·7	= 1690
	Approximate height	2337
Temperature of the air above.....	75°	
Ditto ditto below.....	83	
	Mean 79 = Multiplier	1·098
	Correct altitude	2·566 feet.
	Mean of Barometer Observations	2·649
	Difference	—83

When the boiling point at the upper station alone is observed, and for the lower the level of the sea, or the register of a distinct Barometer is taken, then the barometric reading had better be converted into feet, by the usual method of subtracting its logarithm from 1·47712 (log. of 30 inches) and multiplying by '0006, as the differences in the column of '*Barometer*' vary more rapidly than those in the '*feet*' column.

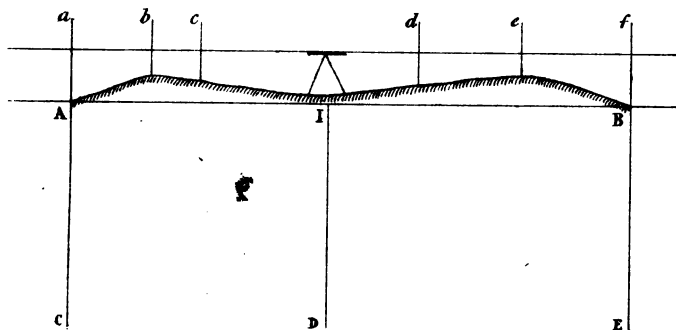
<i>Example.</i> —Boiling point at upper station.....	185°=	14548
Barometer at Calcutta (at 32°) 29 in. 75°		
Logar. diff.=1·47712—1·47349=00363	×0006=	218
	Approximate height.....	14330
Temperature, upper station, 76° } 80=multiplier,.....		1·100
Ditto lower, 84° }		
	Correct altitude.....	15763

Assuming 30·00 inches as the average height of the Barometer at the level of the sea (which is however too much), the altitude of the upper station is at once obtained by inspection of Table L, correcting for temperature of the stratum of air traversed by Table II.

CHAPTER XXIII.

ON LEVELLING.

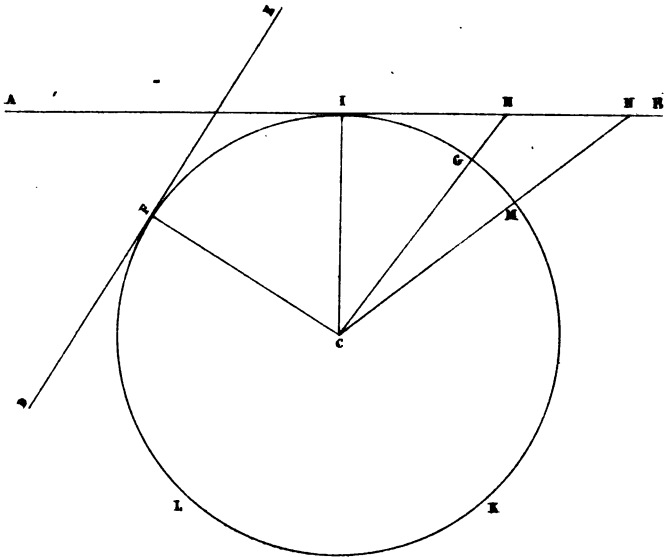
LEVELLING is the art of tracing a line at the surface of the earth, which shall cut the directions of gravity everywhere at right angles. If the earth were an extended plane, all lines representing the direction of gravity at every point on its surface would be parallel to each other; but in consequence of its figure being that of a sphere or globe, they everywhere converge to a point within the sphere which is equi-distant from all parts of its surface; or, in other words, the direction of gravity invariably tends towards the centre of the earth, and may be considered, as represented by a plumb-line when hanging freely, and suspended beyond the sphere of attraction of the surrounding objects.



In the above diagram let the *straight* line *AB* represent the surface of the earth, upon the supposition of its being an

extended plane, the direction of gravity at the points, A , I , and B , would be represented by the lines AC , ID , and BE , all parallel to each other, and at right angles to the horizontal line AB . Now if the surface was undulatory, as shown by the *curved* line AB , and it was required to make a section representing it, an instrument capable of tracing out a line parallel to the horizontal line AB (as a spirit-level) might be set up any where on the surface, as at I , and staves being placed or held along the line, as at a , b , c , d , &c., the different heights above the ground where such staves were intersected by the lines so traced out, would at once show the relative level of all those points, with regard to the horizontal line, as a datum or standard of comparison.

But as the earth is a globe, its circumference must be circular, as IKL , in the annexed figure :



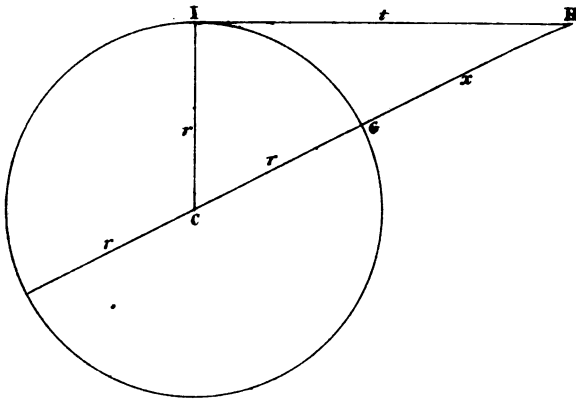
the straight line AB , will therefore not represent the surface of the earth, but the sensible horizon of an observer stationed

at the point I , to which point it is a tangent, being at right angles to the radius of the circle (or semi-diameter of the earth) IC . A line which is parallel to the sensible horizon of the observer, is the line traced out by our spirit-levels, and is a tangent to the earth's surface at that point only where the instrument is set up: thus AB is a tangent at I , and DE a tangent at F ; such being the fact, the difference of level between any two points cannot be determined by simple reference to a horizontal line, since every point on the surface of the globe (however near to each other) has a distinct horizon of its own.

If the earth were everywhere surrounded by a fluid at rest, or that its surface was smooth, regular and uniform, every point thereon would be equally distant from the centre; but in consequence of the undulating form of the surface, places and objects are differently situated, some further from, and others nearer to, the centre of the earth, and consequently at different levels. The operation of levelling may therefore be defined as the art of finding how much higher or lower any one point is than another, or, more properly, the difference of their distances from the centre of the earth.

Referring to our last figure, we have seen that the line AB is a true horizontal or level line at the point I , but being produced in the direction A or B it rises above the earth's surface; and although it may appear to be level as seen from I , yet it is above the true level (which is represented by the circumference of the circle) at every other point, and continues to diverge from it, the further it is produced; at G , the apparent line of level, as the horizontal line AB is called, is above the true level, by the distance GH , and at M by the distance MN , *the difference being equal to the excess of the secant of the arc of distance above the radius of the earth.*

The difference, GH or MN , between the true and apparent level may be thus found. Put t in the following diagram



for the tangent IH , r for the radius CI of the earth and x for GH , the excess of the secant of the arc of distance above the radius; IH being considered as equal to IG ; then

$$\begin{aligned}(r + x)^2 &= r^2 + t^2 \\ \text{or } r^2 + 2rx + x^2 &= r^2 + t^2 \\ \text{and } 2rx + x^2 &= t^2 \\ \text{or } (2r + x)x &= t^2\end{aligned}$$

But because the diameter of the earth $2r$ is so great with respect to the quantity (x) sought at all distances to which a common levelling operation usually extends, that $2r$ may be taken for $2r + x$ without sensible error; we then have

$$\begin{aligned}2rx &= t^2 \\ \text{and } x &= \frac{t^2}{2r}\end{aligned}$$

Or in words: The difference (x) between the true and apparent level is equal to the square of the distance (t^2) divided by the diameter of the earth ($2r$) and consequently is always proportional to the square of the distance.

The mean diameter of the earth is 7916 miles and the excess of the apparent above the true level for one mile

$\frac{t^2}{2r} = \frac{1}{7916}$ of a mile, or 8.004 inches, at two miles it is four

times that quantity or 32.016 inches,* and so on increasing in proportion to the square of the distance.

If we reject the decimal .004 and assume the difference between the true and apparent level for one mile, to be exactly 8 inches, or two-thirds of a foot, there arises the following convenient form for computing the correction of level due to the curvature of the earth, for distances given in miles, viz.,

$\frac{2 D^2}{3}$, D being the distance in miles.

A very easily remembered formula, derived from the above for the correction for curvature in *feet* is two-thirds of the square of the distance in *miles*; and another, for the same in *inches* is *the square of the distance in chains divided by 800*.

But the effect of the earth's curvature is modified by another cause, namely, refraction. This, as regards celestial objects, has already been explained in part 2nd, page 155, and is equally applicable to our present subject. The distance at which an object can be seen by the aid of refraction, is to the distance at which it could be seen without that aid, nearly as 14 to 13, the refraction augmenting the distance at which an object can be seen by about a thirteenth of itself. Hence to correct the error occasioned by refraction, it will only be requisite to diminish the effects of the earth's curvature, or height of the apparent above the true level, by one-seventh of itself.

The following Table shows the reduction of the apparent to the true level, both for the curvature of the earth only, and also for the combined effects of curvature and refraction.

Table of the difference of the apparent and true level for distances in Chains.

Distance in Chains.	Correction.	
	Curvature in decimals of feet.	Curvature and Refraction in decimals of feet.
1	·000104	·000089
2	·000417	·000358
3	·000938	·000804
4	·001668	·001430
5	·002605	·002233
6	·003752	·003216
7	·005107	·004378
8	·006670	·005717
9	·008442	·007236
10	·010422	·008933
11	·012610	·010809
12	·015007	·012863
13	·017613	·015097
14	·020427	·017509
15	·023450	·020100
16	·026680	·022869
17	·030120	·025817
18	·033767	·028943
19	·037623	·032248
20	·041687	·035732

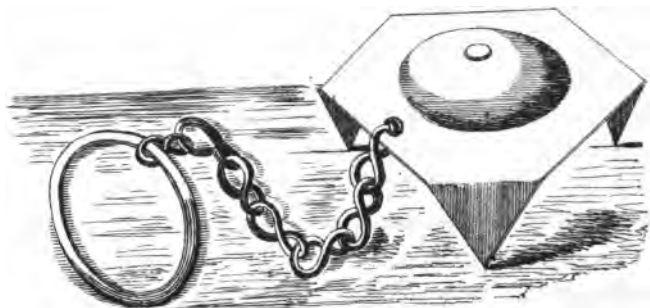
The correction for distances greater than those given in the Table may be computed by the following rule—the same by which the Table itself was computed:

Rule. To the arithmetical complement of the logarithm of the diameter of the earth, or 2.3788603, add double the log. of the distance in feet, the sum will be the log. of the correction for curvature in feet and decimals; from which if one-seventh of itself be subtracted, the result will be the combined correction for curvature and refraction.

Little dependance can however be placed upon the accuracy of any tabulated quantities on account of *terrestrial* refraction,

for when near the horizon it is unequally influenced by the variable state of the atmosphere. The rays are sometimes affected laterally, and they have been even seen convex instead of concave.

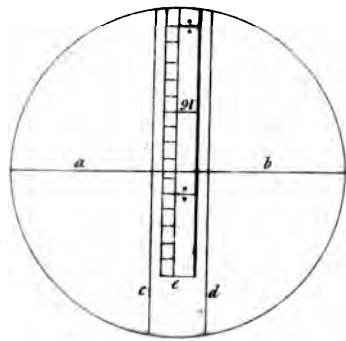
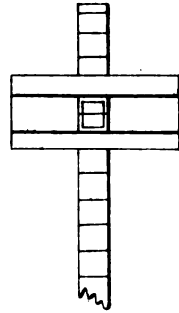
In the 2nd part of this work, we have given a full description of the various instruments used in levelling operations, we will not therefore revert to them here beyond making a few remarks on levelling staves, and also on an instrument of simple construction as represented in the adjoining figure,



its use being to rest the levelling staff upon when held at any station. It consists of a triangular piece of sheet iron, of about one-tenth of an inch in thickness, having the corners turned down to form the feet of the tripod, which are to be pressed into the ground by the foot of the staff-holder; a rounded piece of iron is rivetted on the upper surface, to present a clean spot to rest the staff upon when held at the station; the chain with the attached ring is for the convenience of the staff-holder in lifting it from the ground, and carrying it from station to station; by the use of the above instrument, the staff is sure to be kept on the same spot, and at the same height from the ground while the observer is reading the staves both at the back and forward station on each side of the spirit-level.

The levelling staff, a necessary accompaniment to all levelling instruments, has been hitherto always made with a sliding

vane to move up and down a staff graduated to feet and decimals of feet and inches.* A description of staff has however been lately introduced, by Mr. Gravatt, the face of which is made broad enough to contain sufficiently large graduations and figures, for the observer to read with certainty through the telescope of his instrument to the one-hundredth part of a foot at the distance of 12 chains or more, which is sufficient for most practical purposes, thus securing greater certainty and expedition in the work. A short description of this staff has already been given at page 166, and the only care required on the part of the staff-holder, in using it, is that he may hold it perpendicular. To assist him in this, a small plummet is suspended in a groove cut out in the side of the staff, by which its verticality can be determined in one direction, and the observer himself can detect if it be held aslant in the other direction, as may be understood from the adjoining diagram, which represents the staff *e* as it appears in the field of an inverting telescope, where *ab* represents the horizontal wire, *c* and *d* two wires placed at right angles to it, and separated so as to admit at usual distances, the staff *e* to appear between them and by which the observer can tell if the staff-man holds it erect in a lateral direction.

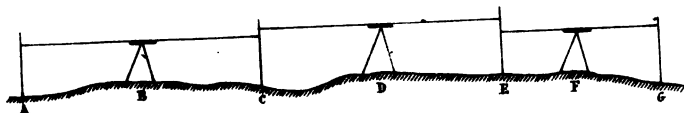


* This was effected by a string and pulley, or the staff itself was made in two or three pieces, each of the upper pieces sliding in a groove in the one next below it. For any height less than the length of the first piece (generally about 6 feet) the vane was slid up or down with the hand; but for a greater height, the second piece with the vane at the top, was moved up bodily

Levelling staves of the above description are now generally used in India, and are manufactured in the mathematical instrument department. They are better adapted for the climate than the one with vane and vernier, the staff invariably warping, and the vernier coming off, rendering the instrument for the time unserviceable. Any defect caused by the wear of Gravatt's staff can be remedied by the Surveyor himself, the edges being secured by a moulding screwed on, and the face of the staff can be renewed by glueing on new strips of paper with the divisions marked on them, which with the protection of a coat of varnish will make the instrument again serviceable.

From what has been said on the subject of the corrections for curvature and refraction, it is necessary to remark that such corrections are very seldom applied in practice, the observer by the arrangements of his operations doing away in a great degree their injurious effects.

The method adopted in practice, is to place the instrument as near as possible midway between the station staves, the effect of curvature is thus removed, as well as that of atmospheric refraction, as the latter will affect both observations alike, unless under peculiar circumstances of the weather, &c., over which the observer has no control. In an extended line of operations, it can however scarcely ever happen that one placing of the instrument will complete it, a succession of similar operations must therefore be performed, as shown in the annexed figure.



till the centre of the vane was cut by the line of the optical axis of the instrument, when the height was read on another scale graduated downwards from the top on the side of the lower joint of the staff.

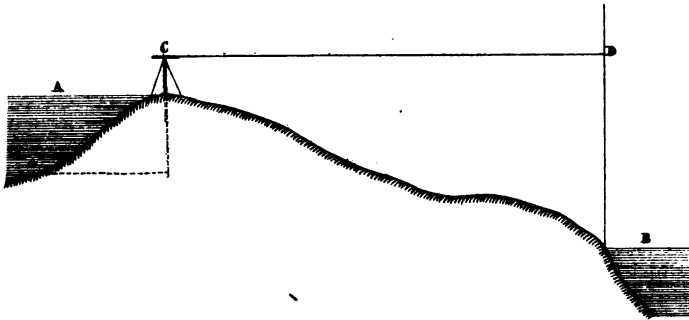
Suppose it were required to find the difference of level between the points *A* and *G*; a staff is erected at *A*, the instrument is set up at *B*, another staff at *C*, at the same distance from *B*, that *B* is from *A*, and the readings of the two staves are noted. The instrument is then conveyed to *D*, and the staff which stood at *A*, is now removed to *E*, the staff *C*, retaining its former position, and from being the forward staff at the last observation, is now the back staff: the readings of the two staves are again noted, and the instrument removed to *F*, and the staff *C*, to the point *G*, the staff at *E*, retaining the same position now becomes in its turn the back staff, and so on to the end of the work, which may thus be extended many miles: the difference of any two of the readings will show the difference of level between the places of the back and forward staff; and the difference between the sum of the back sights, and the sum of the forward sights will give the difference of level between the extreme points thus:

	<i>Back Sights.</i>		<i>Fore Sights.</i>
	<i>Ft. Dec.</i>		<i>Ft. Dec.</i>
A, and C,	10·46	—	11·20
C, „ E,	11·33	—	8·00
E, „ G,	7·42	—	7·91
	<hr/>		<hr/>
Sums	29·21	—	27·11
	<hr/>		<hr/>
	27·11		
	<hr/>		
Difference of level	2·10		

showing that the point *G*, is 2 feet, and $\frac{10}{100}$ higher than the point *A*.

The foregoing process is called compound levelling. The following is an example of simple levelling, being performed

at one operation and therefore subject to the correction for curvature and refraction to obtain a correct result.



If it were required to drain a Jheel *A*, by making a cut to a stream at *B*, a distance of 20 chains: let a level be set up at *C*, and directed to a staff held upright at the edge of the water at *B*. The horizontal line *CD* represents the line of sight which would cut the staff at *D*, the reading being 17.44 feet; the height of the instrument above the ground was 4 feet, and the depth of the Jheel 10 feet; therefore the difference of level between the bottom of the Jheel and the surface of the stream was as follows:

				<i>Ft. Dec.</i>
Reading of the Staff,	...	...		17.44
Height of Instrument,	...	...		4.00
Depth of Jheel	...	...		10.00
Curvature and Refraction for 20 Chs.	...	...		0.03
(see Table page 486,)	...	...		14.03
Difference of level,	...	...		3.41

The following will explain the method to be pursued in levelling a tract of country.

In the first instance the staff-holder must place his staff on the bench mark* from whence the levels are to commence.

* In the practice of levelling, it is usual to leave at convenient intervals, what are called *Bench marks*; these mostly consist of permanent objects, such as stumps of trees, milestones, etc., on which it is usual to cut a distin-

The Surveyor must then set up his spirit-level in the most suitable spot which presents itself, from whence he can have an uninterrupted view, not only of the staff at the back station, but also for a considerable distance in the direction he wishes to carry his levels. The station selected should not in any case exceed 4 or 5 chains, for when long distances are taken, unless both the back and forward stations are equally distant from the instrument, errors will gradually creep in, which in a long series of levels, are liable, by their accumulation, to be of serious consequence.

The proper station being determined on, and the level adjusted for observation* it must be directed to the back staff and the foot and decimal fraction of a foot, with which the central part of the horizontal wire appears to be coincident, noted with all possible exactness, and entered in the proper column of the Field or Observation Book; as soon as it is registered, look to see that the spirit bubble has not returned from its central position, and then repeat the observation, to ensure that no mistake has been made in noting it.

guishing mark, that it may be known hereafter. Their use is chiefly for future reference, in the event of its being necessary, either to check the levels by repetition, to change the direction of the line of levels from any point, or to take up and continue the levels at the commencement of a day's work, a Bench mark having been left at the close of the day preceding.

* The level must be adjusted for observation in the following order: First draw out the eye-piece of the Telescope till the cross-wires are perfectly defined; then, directing it to the staff, turn the milled-headed screw A, (see figure page 159) on the side of the Telescope, till the smallest graduations on the staff are likewise clearly distinguishable, that these two adjustments be very carefully and completely performed is of more consequence than is generally supposed, for upon them depends the existence or non-existence of parallax to remove which has already been explained at pages 161 and 162. The above adjustments being made perfect, bring the spirit bubble into the centre of its glass tube, and which position it must retain unmoved in every direction of the instrument; this is accomplished in the same manner as in the Theodolite by bringing the Telescope successively over each pair of the parallel plate screws, and giving them motion, screwing up one, while unscrewing the other to an equal extent.

The back observation being made, turn the Telescope round in the forward direction; then look at the spirit bubble, and if it has at all changed its position, by receding towards either end of the tube, bring it back to the centre by the parallel plate screws, then observe what division on the staff is intersected by the cross-wire, and enter the reading in the proper column of the Field-book. Having entered it, verify it by a second observation, which will complete the first levels. The first levels being completed, the Surveyor passing the man who holds the forward staff, proceeds to some convenient spot to set the instrument a second time, which, as before remarked, should not be more than 4 or 5 chains distant; the man who held the staff at the back station, likewise proceeds still further onwards to take up a new station, and as nearly as possible at the same distance from the instrument, as the instrument is from the staff, which has now become the back station. The instrument is then again adjusted, and the same process followed as above described, until arrived at the end of the series.

The foregoing description of the method of taking levels is general, and applies equally to every kind of levelling operation.

The following is the form of Field-book used for entering the observations, &c.

Form of Field-book for Observations.

No. of Station.	Back Level.		Back Bearing.		Back Distance.		Height of Instrument.		Fore Bearing.		Fore Distance.		Fore Level.		From 1st Station in the Series.		Results.		Remarks.
	Ft. Dec.	° ' "	Ch. Lks.	Ft. Dec.	° ' "	Ch. Lks.	Ft. Dec.	° ' "	Ch. Lks.	Ft. Dec.	Ft. Dec.	Ft. Dec.	Rise.	Fall.	Rise.	Fall.			
1	13·71		205·30	5·19	3·40	25·20	7·96	7·88	5·83	5·83							Commenced from bench mark on Tal Tree, N.E. corner of Mundulpoore Tank, 100 feet above datum.
2	9·40		208·15	2·27	3·60	25·10	3·08	16·30	....	1·07	....	6·90						
3	3·87		207·10	5·08	3·70	23·20	3·40	11·71	....	8·91	....	7·84						
4	2·63		206·40	6·59	3·70	28·25	4·00	12·41	....	18·69	....	9·78						
5	14·62		205·10	3·92	3·80	26·15	5·20	0·95	...	5·02	13·67	....						
6	17·00		208·30	4·64	3·95	29·30	3·89	1·45	10·53	....	15·55	....						

Where levels are made for the formation of a section it is necessary that the distance between the levelling staves be measured, as well as the bearing observed of each staff to enable the Surveyor to plot and draw the section, but in running or check levels there is no necessity for the chain or compass, the object of check levels being only to obtain the difference of level between certain intermediate and the extreme points of the section previously made, to check its accuracy. It is also immaterial by what route we proceed from one point to another, so that such spots may be selected for the stations as are most convenient for the purpose, and may afford opportunity of checking any intermediate points on the section line. The Field-book required therefore for check levels is merely a simple entry of back and fore sights, the difference of the sums of which will be the difference of level between the extreme points of the Section line.

Form of Field-book for check levels.

Stations.	Back Sights.	Fore Sights.	Remarks.
1	4.19	4.24	Back station on bench mark at milestone 72.
2	5.44	1.20	
3	4.96	3.20	Forward station top of milestone 87.
4	4.73	1.32	
	19.32	9.96	Sums.
	9.96		
	9.36	Difference.	

It is usual to refer all levels to a certain datum line, previously fixed, and in the course of a long series of levels, to keep a register of the heights of particular spots, above this given datum, which may be considered as so many zero or fixed points, easily recognizable, if carefully noted in the Field-book, and from whence any portion of the work can be levelled over again,

or branch lines of level be conducted in any direction, and the levels of such branches be comparable with those of the main line.

This datum line should invariably be assumed from some known and fixed *permanent* point which may always be referred to, without the chance of doubt and misconception at any subsequent period. For instance, the recent levels of the town of Calcutta, taken by Mr. Simms, the Consulting Civil Engineer to Government, are all calculated from the bottom or sill of the stone on the Tide Gauge at Kyd's Dockyard, a point which must always be easy of ascertainment, and which is peculiarly convenient for comparison with the mean level of the sea.

This point of the Tide Gauge has been ascertained to be 8.38 feet *below* the sea level, by a series of observations of the heights of the tides at Calcutta at high and low water, from which the lowest monthly average of the mean tidal level in the months of February and March, has been assumed as the mean level of the sea.

The observations made for this purpose tend to show that the locality of Calcutta is unfavorable for determining with great precision the mean sea level, owing perhaps to the length of the channel which the tides have to traverse, and the great effect produced by the rise of the river in the monsoons, the difference of the mean height in the month of September being $6\frac{1}{4}$ feet above that of February or March.

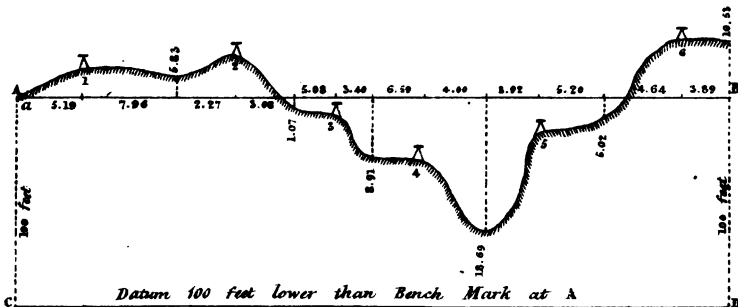
But these disturbing causes are, for the most part, independent of the influence of the sea itself, the monthly mean tide of which should be an uniform quantity affected only to a slight degree by the pressure of the wind. Divested of these anomalies it may be concluded that the mean state of the water in the river can never be *lower* than the actual sea level, the lowest monthly average of mean tide is therefore perhaps the nearest approximation to the truth.

According to these levels, the surface of the mercury in the cistern of the Standard Barometer in the Calcutta Obser-

vatory* is 18·21 feet, and the floor of the large puckha Ghat, inscribed to Lord William Bentinck and known as "Baboo's Ghat," exactly 17·79 feet *above* the mean level of the sea.

When a line of levels of any considerable length is to be plotted, the horizontal distances cannot be laid down on as large a scale as is necessary for the vertical heights above the datum point, in order that the section may be of any practical use, without making the plot of most unwieldy dimensions. It is therefore usual to make the vertical scale much larger than the horizontal one: thus 4 inches to a mile for the horizontal distances, with one inch to 100 feet, for the vertical distances, is an usual combination; the vertical scale being so much greater than the horizontal, shows the depths of cutting and embankment required in the execution of roads, railways, canals, &c., with greater clearness than if both scales were equal.

For instance, to plot the line of levels as given in the Field-book, page 493.



Draw a line *AB* representing the horizontal line as the datum to which the levels are reduced, as shown in the column headed "From 1st Station in the series," assume any point *a* as the starting point from which set off the measured distances, as given in the back and fore distance columns, at these several

* The *old* Observatory No. 19, Chowringhee Road, is here alluded to. The present Observatory is situated at No. 35, Park-Street, where it originally stood.

points raise perpendiculars, and on them lay off the differences of level from the 1st in the series; join these several points, and the section is completed.

The section being 100 feet above the previously fixed datum point, all that is required to represent this, is to draw a line *CD*, parallel to *AB*, at 100 feet below it, then by drawing perpendiculars from the surface line to this new datum, as shown by the dotted lines, the transfer will be complete, as the heights of any points can be measured by the scale of the section. In plotting sections, it is the *horizontal* distances between the several stations that must be laid down. When the ground rises and falls in long regular slopes, the measurement as taken along the slopes, must be reduced to horizontal distances by calculation. If the rise or fall is but slight, this reduction may be altogether disregarded, the difference between the horizontal and hypotenusal measurements not exceeding the limits of error in the measure itself.

The following Table, showing the reduction to be made on each chain's length, will assist in making the necessary calculation.

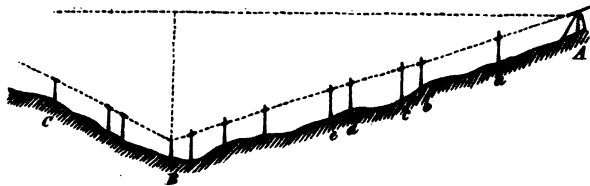
Rise in feet for one chain.	Reduction upon one chain in links and decimals.
1	0·01
2	0·04
3	0·11
4	0·19
5	0·29
6	0·44
7	0·56
8	0·74
9	0·94
10	1·16
11	1·40
12	1·76
13	2·01
14	2·24
15	2·61
16	2·99
17	3·39
18	3·76
19	4·23
20	4·64

Levelling with Theodolite. The application of the Theodolite to the practice of levelling is an operation of great simplicity.

The instrument is set up at one extremity of the line previously marked out by banderoles or long pickets at every change of the general inclination of the ground; and a levelling-staff, with the vane set to the exact height of the optical axis of the Telescope, being sent to the first of these marks, its angle of depression or elevation is taken, and by way of insuring accuracy, the instru-

ment and staff are then made to change places, and the vertical arc being clamped to the *mean of the two readings*, the cross-wires are again made to bisect the vane. The distances may either be chained before the angles are observed, marks being left at every irregularity on the surface where the levelling-staff is required to be placed; or both operations may be performed at the same time, the vane on the staff being raised or lowered till it is bisected by the wires of the Telescope, and the height on the staff noted at each place.

The accompanying sketch explains this method:—*A* and *B* are the places of the instrument, and of the first station on the line, where a mark equal to the height of the instrument is set up; between these points the intermediate positions *a*, *b*, *c*, *d*, for putting up the levelling-staff are determined by the irregularities of the ground. The angle of depression to *B* is observed, and if great accuracy is required the mean of this and the



reciprocal angle of elevation from *B* to *A* is taken, and the vertical arc being clamped to this angle, the Telescope is again made to bisect the vane at *B*. On arriving at *B*, after reading the height of the vane at *a*, *b*, *c*, &c., and measuring the distances *A a*, &c., the instrument must be brought forward, and the angle of elevation taken to *C*, the same process being repeated to obtain the outline of the ground between *B* and *C*. In laying the section down upon paper, a horizontal line being drawn, the angles of elevation and depression can be protracted, and the distances laid down on these lines; the respective height of the vane on each staff being then laid off from these points in a *vertical direction*, will give the points

a, b, c, &c., marking the outline of the ground. A more correct way of course is to calculate the difference of level between the stations, which is the *sine* of the angle of depression or elevation to the hypotenusal distance *AB* considered as radius allowing in long distances for curvature and refraction.

Instead of only taking the single angle of depression to the distant Station *B*, and noting the heights of the vane at the intermediate Stations, *a, b, c, &c.*, angles may be taken to mark the same height as the instrument set up at *each of these intermediate points*, which will equally afford data for laying down the Section; but the former method is certainly preferable.

The details may be kept in the form of a Field-book, but for this species of levelling the measured distances and vertical heights can be written without confusion on a diagram, leaving the corrections for refraction and curvature (when necessary) to be applied when the section is plotted.

Where a number of cross sections are required, the Theodolite is particularly useful, as so many can be taken without moving the instrument. It is also well adapted for *trial sections*, where minute accuracy is not looked for, but where economy, both of time and money, is an object.

The Theodolite is likewise used in running *check levels*, to test the accuracy of those *taken in detail with a spirit-level*. Reciprocal angles of elevation and depression, taken between bench marks, whose distances from each other are known, afford a proof of the general accuracy of the work; and if these points of reference are proved to be correct, it may safely be inferred that the intermediate work is so likewise.

CHAPTER XXIV.

ON CONTOURING.

ANOTHER species of levelling to be described, is that by which certain data are given, from which the outline of a horizontal section of the ground can be constructed and is called "Contouring," a term which is applied to the outline of any figure and consequently to that of any section of a solid body, but when used in connection with the forms of ground or of works of defence, the outline of a horizontal section of the ground, or works, is alone to be understood by it.*

Contour lines give a most perfect delineation of the ground, and they are the only part of a Survey which will remain unaltered in the lapse of ages, hills and valleys being much more permanent things than houses, roads and boundaries, which cease to give accurate information in a few years and require revision at a great cost.

It would be useless expense to increase the number of Contour lines on mountain ground where no probable demand either for roads or drains exists, and on the other hand in districts which are nearly level, Contours only at great difference of altitude would be of little practical utility.

In waste lands, Contours tend to a knowledge of the best mode of improvement, as the levels are connected with each other throughout the country, and referred to the sea as a datum line. As a general system, however, Contouring can

* *Vide* Note page 509

scarcely be said to be applicable to India, where the mountains are inaccessible and for the most part untrodden, and the wastes impenetrable and impervious, from the denseness of the jungle and rankness of the vegetation. The undulations and round smooth downs of England are here wanting, and the vast extent of the country leaving but few points fixed by the great triangulation, the operation, so simple on the Ordnance Survey of England, would be one of much difficulty in this country, where there is so little to mark the inequalities of the surface until the stupendous hills rise suddenly and precipitously above the general level.

A few remarks on the system, however, which has become so common in England, will not be misplaced.

“ The method of tracing these Contours in the field is thus performed. Banderoles or long pickets are first driven, one at the top and another at the bottom of such slopes as best define the ground, particularly the ridge lines, and watercourses, should no such *sensible* lines exist, they must be placed at about equal intervals apart, regulated by the degree of minutiae required, and the variety in the undulations of the surface of the ground. A short picket being driven on the level of the intended upper (or lower) line of Contours, and in line between two of the banderoles, the level is placed so as to command the best general view of this first line and adjusted, care being taken that its axis is not so low as to cut the ground below the picket (or so high as to be above the top of the levelling-staff, if the lower Contour is the first traced); the staff is then placed at this picket, and the vane raised or lowered till it is intersected by the cross-wires of the Telescope, the staff is then shifted to another point on about the same level, and in the line between the next two pickets, and the staff itself moved up or down the slope till the vane again coincides with the cross-wires, at which spot another picket is driven. This operation is continued, till it is necessary to move the level to continue the same upper Contour lines, when (the staff being

placed at one of the pickets just driven) the vane is again raised or lowered to suit the next position of the axis of the instrument and kept at this height, as before, for the continuation of the line. To trace the next lower Contour line, it is merely necessary to raise the *vane* on the staff, five, ten, or whatever number of feet may be the vertical distance determined upon, and proceed as before. When the level itself has to be moved to lower ground, it must be so placed that its axis will cut the ground above one of the pickets of the line just marked out, and the same quantity of five or ten feet added to the reading of the staff at this picket, will give the height of the vane for the next lower horizontal line.

“The use of driving all these pickets, marking out the Contours nearly in the same line down the slopes, becomes evident when they are to be laid down on the plan, the places of the original banderoles or long pickets being fixed with reference to each other, it is only necessary to measure between them, entering the distances on these lines, with the offsets to the right or left to the different short pickets marking the horizontal lines.”*

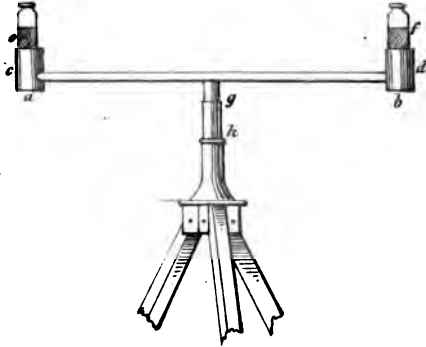
* The instrument, best adapted for Contouring where a rapid delineation of country is an object frequently of greater importance than accuracy, is the *water-level*, its best recommendation being the facility with which it can be made and requiring no adjustment when using it. The following description is taken from “Frome on Surveying.”

The French *water-level* is much used, on the continent, in taking sections for military purposes. It possesses the great advantage of *never requiring any adjustment*, and does not cost the one-twentieth part of the price of a spirit-level. From having no Telescope, it is impossible to take long sights with this instrument; and it is not of course susceptible of *very minute accuracy*: but, on the other hand, no gross errors can creep into the section, as may be the case with a badly adjusted spirit-level, or a Theodolite used as such, the horizontal line being adjusted by nature without the intervention of any mechanical contrivance. As this species of level is not generally known in England, the following description is given; which, with the assistance of the sketch, will enable any person to construct one for himself with-

“Contoured plans from which sections are to be constructed are generally plotted on about the same scale as special surveys of estates, that is, on one of 2, 3, or 4 chains, to one inch. Small portions of ground for military purposes where the ver-

out further aid than that of common workmen to be found in every village.

a b is a hollow tube of brass about half an inch in diameter, and about three feet long, *c* and *d* are short pieces of brass tube of larger diameter, into which the long tube is soldered, and are for the purpose of receiving the two small bottles *e* and *f*, the ends of which, after the bottoms have been cut off by tying a piece of string round them when heated, are fixed in their positions



with putty or white lead—the projecting short axis *g* works (in the instrument from which the sketch was taken) in a hollow brass cylinder *h*, which forms the top of a stand used for observing with a repeating circle; but it may be made in a variety of ways so as to revolve on any light portable stand. The tube, when required for use, is filled with water (coloured with lake or indigo), till it nearly reaches to the necks of the bottles, which are then corked for the convenience of carriage. On setting the stand tolerably level by the eye, these corks are both withdrawn (which must be done carefully and when the tube is nearly level, or the water will be ejected with violence) and the surface of the water in the bottles being necessarily on the same level, gives a horizontal line in whatever direction the tube is turned, by which the vane of the levelling-staff is adjusted. A slide could easily be attached to the outside of *c* and *d*, by which the intersection of two cross-wires could be made to coincide with the surface of the water in each of the bottles; or floats, with cross hairs made to rest on the surface of the fluid in each bottle, the accuracy of their intersection being proved by changing the floats from one bottle to the other: either of these contrivances would render the instrument more accurate as to the determination of the horizontal line of sight; though one of its great merits, quickness of execution, would be impaired by the first, and its simplicity affected by either of them. For detailed sections on rough ground, where the staff is set up at *short distances apart*, it is well qualified to supersede the spirit-level; and is particularly adapted to tracing *Contour lines*.

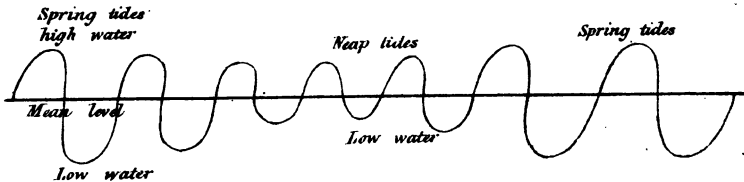
tical distances are under five feet may even be laid down on a scale of one chain to one inch.”*

The method adopted in carrying on the Contours of the Ordnance Survey of England is detailed in the following memorandum obtained from the Ordnance Map Office at Southampton, and which gives a clear explanation of the subject.

“By the aid of Contours we obtain such a perfect knowledge of the configuration of the country, that every map may be said to be a model of the district, and their advantage increases in proportion as the area to be examined is extended.

“The Contour lines are formed by connecting points of equal altitude determined by levelling, and traced through any district; they are placed at equal altitudes above each other as at 25, 50, 100 feet, &c., depending upon the nature of the country, and these are taken above a given datum level.

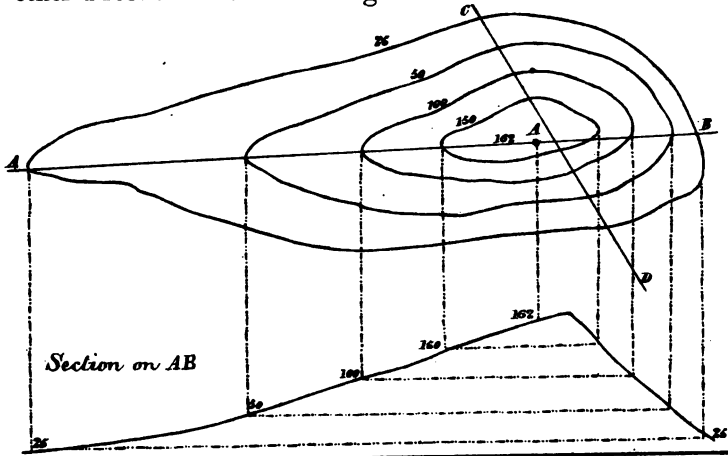
“The mean level of the sea is found to be a more constant level round this kingdom.



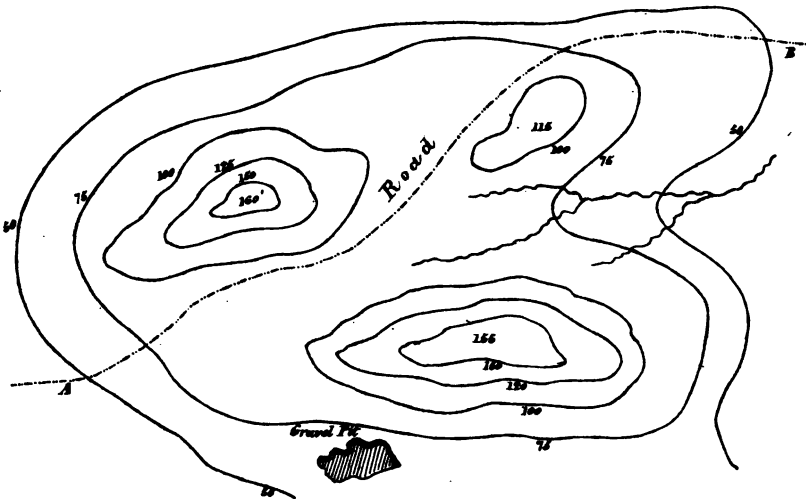
“The tides from the springs to the neaps may be said to oscillate above and below the mean tidal line, and it is found that although the rise and fall of the tides varies in amount round the coast, the mean tidal line is nearly a constant level, and it is therefore a much better line of reference for the Contours than any other.

* *From* on Surveying.

“ To illustrate the principles of Contouring, first take as an example an isolated hill or an island and the section in any other direction as *CD* can be given at once.



“ Take an example of a supposed more extensive district, and that other Contours are interpolated by the eye, which can be done with great accuracy where there is so much fixed data.



“ The line which a road should take from *A* to *B* may be determined better in the closet than on the ground, and with-

out having reference to local surveys made too frequently under the dictation of local influence, to obtain a particular object, and in disregard of the interests of the community who have to pay for the construction and maintenance of the road.

Contouring. "The Contouring on the Ordnance Survey is divided into six branches, viz.

1. Initial levelling.
2. Road and Trigonometrical line levelling.
3. The Contouring.
4. Plotting.
5. Examining.
6. Hill Sketching.

"The initial levelling is the first operation, and is the basis of all the rest. It consists in levelling with a superior instrument, the main roads in any district of country, leaving permanent marks (either copper bolts or bench marks on masonry) the value of which, in altitude, is most accurately fixed by twice or even three times levelling. The work is kept in Field-books and the leveller makes a survey of the road as he works, in order that the position of the marks and altitudes may be correctly plotted on the plans when made. The instruments, used on the survey, are 12-inch spirit-levels.

"This levelling has been carried on to a considerable extent in England and Scotland, and is much in advance of the Contouring.

2nd. "Road and trigonometrical line levelling for Contour purposes, is built upon the initial levelling and depends upon it.

Road and trigonometrical line levelling.

"The books of the initial levelling having been worked out at the map office, a correct list of the marks and their values is furnished to the district office for any district required to be Contoured.

“ This district is then carefully perambulated, and such roads as pass over important features of ground are levelled with a second rate instrument (a 10-inch or 5-inch Theodolite.) As it is found that roads generally keep to the valleys and are not so useful for Contouring purposes when levelled as lines at right angles to the general run of Contours, recourse is had to trigonometrical line levelling, that is to say, lines of levels are run from one trigonometrical station to another, crossing the general run of Contours at right angles as nearly as possible.

“ Sometimes a road may be found that goes directly up a hill, and then it is invariably used for levelling purposes in preference to a trigonometrical line, on account of the facility in working on it compared to levelling in fields; wooden pickets are left along these lines wherever there is no means of making a bench mark on masonry, and the values given in levelling have reference to the tops of these pickets. This Contour levelling depends upon the initial road levelling inasmuch as it starts from some mark on one initial line, and closes on some other mark.

3rd. “ The non-commissioned officer in charge of a section of Contourers, has a list given him of the marks in the district he is employed upon; when he requires
 Contouring. any particular Contour line laid down, he furnishes the party who is to do it with the position and value of the nearest mark to the required altitude on a levelled line; this is used for a starting point and having risen or fallen from this mark till he has obtained the Contour height, he proceeds to lay out the Contour line by rods fixed in the ground as a temporary mark, at the same time he surveys the position of these rods with reference to the detail shown on a plan furnished to him, and enters the survey in a Field-book.

“ At certain convenient places on his Contour line he leaves wooden pickets which enable his work to be tested afterwards,

his plan until the whole is completed,—this work is not kept in Field-books.

“ The instrumental Contours hitherto run have been the 25 feet—50—100—150—200—250—300—350—400—500—600—800—1000—1200—1400—&c. &c.

“ Whilst the Contours interpolated have been the 75 feet—125—175—225—275—325—375—425—450—475—525—550—575—625—650—675—700—725—750—775—825—850—875—900—925—950—975—1025—1050—&c. &c.”

In further elucidation of this subject, we have extracted the article by Captain Harness, Royal Engineers, from the *Aide Mémoire*, vol. 1, page 227, as given in the foot notes—

CONTOURING.

This term is applied to the outline of any figure, and consequently to that of any section of a solid body ; but when used professionally in connection with the forms of ground, or of works of defence, the outline of a horizontal section of the ground, or works, is alone to be understood by it.

When the forms of ground or works are described by Contours, or horizontal sections, these sections are taken at some fixed vertical interval from each other suited to the scale of the drawing, or to the subject in hand ; and the distance of each, above or below some assumed plane of comparison, is given in figures at the most convenient places on the plan. When the scale of the drawing is about 100 feet to an inch, 2 or 3 feet will be found a convenient vertical interval between the Contours ; and however large the scale of the plan, it will scarcely be found necessary to obtain Contours with a less vertical interval than 2 feet. If the scale of the plan be about 250 feet to an inch, or the ordinary special survey scale of 4 chains to an inch, 5 feet will prove a convenient vertical interval ; and with a horizontal scale of from 500 to 800 feet per inch, 10 feet may be taken as the vertical interval. The French generally employ an imaginary plane of comparison above the highest points in the plan ; but there does not appear to be any good reason why the figures, which would denote the altitudes of the several points of a plan above the level with which they are usually and naturally compared, should not be employed to denote the levels of the Contours. Near the coast, the level of low water, the plane of comparison for the soundings in nautical charts, is the natural plane of comparison for Contours ; and the numbers affixed to them, when this is adopted, express their altitudes in the ordinary way.

streams, &c. ; and determine carefully the altitudes of the trigonometrical points employed above the intended place of comparison. Take an accurate trace from the plot of one of the triangles, which, if the distances between the trigonometrical points are properly proportioned to the scale of the plan, will generally be a convenient piece in point of size to Contour. Take this trace to the ground, and find upon the ground, and mark upon the trace, the points where each of the intended Contours will cut the boundary lines of the triangle.

Suppose the level of a trigonometrical point A (fig. 6, Plate XI.) to be 273½ feet, that the ground is falling towards B, and rising towards C, the third angle of the triangle : if the Contours are to be at 5-feet vertical intervals, 270 feet will be the level of the next below A, and 275 feet of the next above A ; the surveyor therefore must find a point 3½ feet lower than A on AB, and another 1½ foot higher than A on AC.

Put up a Theodolite near A, and using it as a level, read the levelling staff when it is held at A ; add 3½ feet to this reading, and send the staff along the line AB until the vane agrees with the horizontal wire of the Telescope ; the point where the staff then stands will be 3½ feet lower than A, and will be the intersection of the Contour at the level 270 with the line AB.

To find the first point on the line AC, diminish the reading at A by 1½ foot, and send the staff towards C, in like manner.

It is most convenient to mark the intersections of the Contours with one boundary line at a time: if the ground be falling along that line, after a point in a Contour is fixed, add the intended interval between the Contours to the reading on the staff at that point, and the place where it stands when the vane agrees with the horizontal wire of the Telescope of the instrument will be a point in the next lower Contour; and so long as the staff will admit the addition of the interval, the successive Contours may be marked without moving the Theodolite: this would be the method in proceeding along AB, from A to the level 200. If the ground be rising, choose a place for the instrument as much above the last point fixed as will bring the Telescope nearly on a level with the vane when raised to its highest position, or with the top of a levelling staff without a vane ; and then by continually deducting the interval, the intersections with the line of several Contours may be marked after each removal of the instrument: this would be the process from the level 200 to B.

The levels of the trigonometrical points check the above operation, and if after marking all the points along one of the boundary lines, it is found that the position of the last is incorrect with reference to the assigned level of the neighbouring trigonometrical point, the cause of the error should be ascertained, and the error corrected before proceeding further.

To trace the Contours between the points established upon the boundary lines, put up the instrument at some point easily fixed upon the trace, from which at least one end of the portion of Contour to be traced can be seen, and

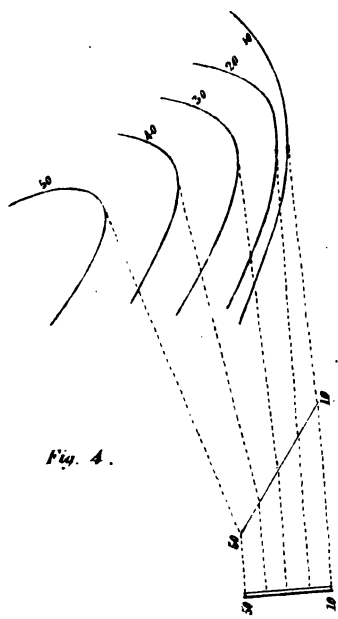


Fig. 4.

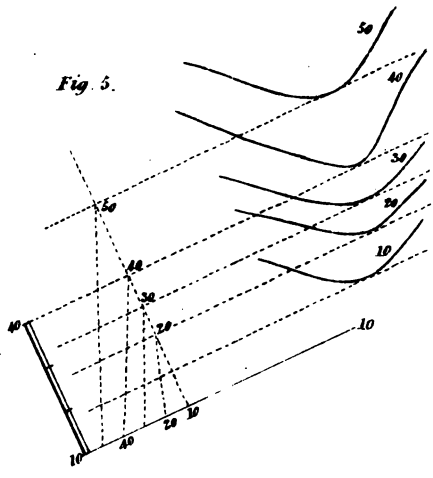


Fig. 5.

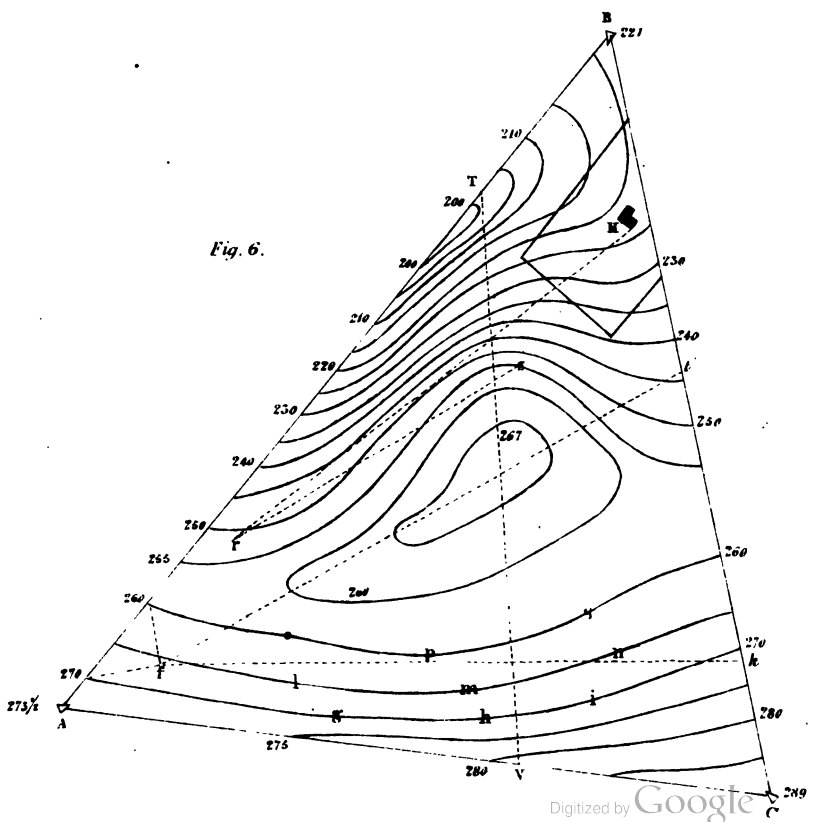


Fig. 6.

neither too high, nor too low, to permit the staff being read when held upon the Contour. Send the staff to the visible extremity of the Contour, and read the level; move the staff in the direction of the Contour, and every point where the same reading is obtained, with the same position of the instrument, will be a point in it. When as many points have been fixed as are necessary to trace the part of the Contour visible from the instrument, take the angle between the last point fixed and some point given in the trace, unless the situation of the last point is known by being close to some object given in the trace; lay down the direction of the line from the instrument to the last picket; chain the line, fixing the points of Contour by offsets, as they are successively passed; and add the work to the trace as it proceeds.

Thus if the true instrument be placed at f , (fig. 6) its position may be fixed by measuring its distance from each of the pickets marked 260 and 270; the staff being read, or adjusted when held at 270, may be moved to g , h , i , and 270 (as a check) in the boundary line BC , the exact place for the picket at g , h , or i , being determined by moving the staff up or down the slope until the reading on the staff is the same as at 270 in the line AB .

With the same position of the instrument, if the staff be about 12 feet in length, the points l , m , n , in the Contour 265, and the points o , p , q , in the Contour 260, might be established, the staff being read, or adjusted at the picket 265, before it is sent along the former Contour, and at the picket 260, before it is moved along the latter; by measuring the line f , k , these points may be determined by offsets, and the Contours drawn upon the trace. From the same point also, all the pickets required to describe the Contours having the levels 260 and 265, and lying wholly within the triangle, may be fixed, since the Telescope of the instrument would be higher than the summit they surround; and by measuring the line f , t , these Contours could be added to the trace.

It is not necessary to trace every Contour instrumentally: if the Contour 275 has been thus traced, the two between 275 and 260 can be added very correctly by the eye while the Contour 260 is being traced, by judging each time a picket of the latter is fixed upon the trace, how the interval should be divided to accord with the appearance of the ground.

Neither is it always necessary to fix the position of the instrument, for the pickets may often be surveyed without measuring from it; but wherever angles are used to set-off the measured lines it is necessary, and may be considered the general rule.

A single position of the instrument will seldom trace a Contour,—fences, &c., as well as the form of the ground, preventing it. If the instrument were placed at r , to trace the level 255, the last picket would probably be at s , the angle between the corner of the house, H , and the picket, s , might be observed, protracted on the trace, the line measured, the several pickets as far as s added to the plan, the instrument removed to s , and the Contour completed.

But the instrument might, in the case represented, be placed near s , its position being fixed, if necessary, by measurement from any of the points recognized on the trace, as the angles of the adjacent fence; from this point the whole Contour could be traced, neither buildings, fences, nor other objects intervening.

If the triangle be very large, and the Contours inconveniently long, it may easily be divided, and a dividing line should, if possible, be chosen running along one of the ridges of the ground; for the ridges afford the best sites for the instrument in tracing; and the ridges and valleys are convenient situations for check lines, because those measured to survey the pickets having to change their direction in crossing them, can then be closed upon points already fixed. The line TV would be a good dividing line in the figure, running along the ridge on which the point s is marked, and fixing two points in each of the Contours of the summit within the triangle.

- If it be required to Contour a single feature of ground, not as part of a large survey, but for some particular object, run lines from the summit along the several ridges of the ground, fix upon these lines the points where the Contours will intersect them, and trace, as above, the Contours between them: if the number of check lines be too few, run them in the valleys also.

CHAPTER XXV.

ON THE RECESS, OR OFFICE DUTIES OF A REVENUE SURVEY,—PREPARATION AND COMPLETION OF MAPS AND AREAS, REDUCTION OF MAPS, &C.

HAVING described in the previous Chapters the several operations *in the field*, and the extent to which the results are there perfected, it is now necessary to particularize the equally important and laborious duties connected with *the office*, as pursued in the recess months, which, forming a considerable portion of the work to be accomplished within the year, requires no little tact and method to ensure its completion ere a fresh season demands the attention of the Surveyor.

The recess in Bengal, already alluded to at page 310, comprises the months from 1st of June to the middle of November, the rains generally driving the survey parties into the station or cantonments about the former dates, whilst the state of the country prevents an earlier assumption of field duties than the latter named period, or even the 1st of December. In the North-Western Provinces, little can be done in the field in May, whilst the recess terminates as early as the 15th October, by which time the country and climate is very favorable for active operations. During these months, the Surveyors and their establishments are employed in putting the field-work into a complete and tangible form, and preparing the several records and documents called for by Government, it being both expected and exacted, that the whole of the maps and calculations of one season be duly lodged and furnished to the

respective authorities, prior to the commencement of another season's work.

The office duties of a Revenue Survey may be divided into the following heads, and in this order we propose alluding to them :

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|--------------------------------------|---------|---|---|
| 1. <i>Computing.</i> | | 11. <i>Comparing and Examining.</i> | |
| 2. <i>Checking.</i> | | | |
| 3. <i>Plotting</i> | } Maps. | 12. <i>Filling in Village Plan Registers.</i> | |
| 4. <i>Compiling</i> | | | |
| 5. <i>Drawing</i> | | | |
| 6. <i>Reducing</i> | | | |
| 7. <i>Copying.</i> | | | |
| 8. <i>Colouring and Hill shading</i> | | | |
| 9. <i>Printing</i> | | | |
| 10. <i>Finishing</i> | | | |
| | | | 13. <i>Formation of Pergunnah Volumes, with Alphabetical Lists, &c. &c.</i> |
| | | | 14. <i>Division of labor.</i> |

In Chapter X., page 302, we have detailed the mode of calculation pursued, by the system of co-ordinates obtained from the sine and co-sine of the angle, which the side makes with the meridian of every line surveyed, and shown that there are certain *proof* columns of the Traverse Table, to which every circuit must be rigorously subjected *at the time of survey*, so much of the Traverse Table (columns 1 to 9, page 301,) being complete, the field-work is deemed satisfactory, and the remainder may with safety be left to any subsequent period. The plotting columns 10 and 11, or differences of latitude and departure, are then worked down for the purpose of laying down the survey on paper and it has been shown, that where the N., S., E. and W. columns are proved, the protraction of the survey is certain and beyond all doubt, by means of columns 10 and 11 which likewise prove themselves, by coming out 0—0 or by the last differences of

latitude and departure, coinciding with the same items in columns 6 and 8. The three last columns 12 to 14 are entirely for the area, according to the rules previously laid down, but for these there is no check and the products obtained from factors of five places of figures incorrectly calculated, would vitiate the area of the figure.

Accurate areas forming one of the chief objects of a Revenue Survey, every precaution is necessary to ensure this object, and to record them in such a clear and distinct manner that they may always be made available for easy reference, by the authorities of a District. The products, therefore, after being carefully worked by one assistant, require to be checked by another person, either by an independent similar calculation by common multiplication, or by means of a Set of Tables lately published,* the object of which, as stated in the preface, is "to simplify this calculation and to effect, by a short *addition*, what is now obtained by a long and tedious multiplication, as exemplified in the mode of finding areas by the Universal Theorem." When it is remembered that for every line measured, however short it may be, a product has to be worked in one village for that line, and also one in the adjoining village for the same line, it may be easily understood that where in a season's work of some 1,500 to 2,000 villages, 30 or 40,000 separate calculations have to be made to obtain the area, errors will occasionally creep in, notwithstanding every care.

The products having been worked and compared, it remains to place them in the Table in their respective columns, positive or negative, according to the rules laid down in Chapter IX. In this step there is also a chance of error and it is obvious that any product misplaced vitiates the total area by a sum equal to double that quantity.

* Multiplication Tables from one link to one hundred Chains, compiled for the use of the Revenue Surveys in India. By a Revenue Surveyor, Calcutta, 1848.

The correct areas of all the right lined figures, or *within station lines*, having thus been computed, the *offsets*, or quantities subtended by the sinuosities or irregularities of the boundaries *within* and *without* these station lines, remain for consideration. These may be calculated as directed in Chapter V., and the results of each side of a circuit common to two villages, or as it is called *between each tri-boundary* duly recorded on the rough office map, additive for one village, and subtractive for the other, each tri-boundary being completed, the balance area of offsets for the entire village circuit is at once obtained, and being applied to the Traverse area, according to its proper sign, plus or minus, leaves the true contents of the village. The advantage of noting these computations for offsets on the rough map, or *chudder* as shown in Plate VL, page 336, is, that the eye is able immediately to detect any error in the sign of the quantity, for instance, on the tri-boundary *J* to *B* of Mahmoodpoor, it is evident that the 14 acres must be minus for that village. It also greatly facilitates future reference, and enables the Surveyor to apply the proper quantity for a line common to any two villages without additional trouble.

The computation of all small parcels of land, as interlaced portions of estates and villages, varying from one to 20 acres, as well as of the several details within the village, is always performed on the paper by scale and compass, or by the Talc-Square; and is sufficiently accurate for the purpose required.

The main circuit Tables being complete, the values of the co-ordinate distances of each tri-boundary are extracted, and separately recorded, for the more ready protraction of the extreme points of a pergunnah or main circuit, the length of any side being compared with the same data taken from the computation of the adjoining Traverse, the discrepancy (if any) must be corrected by proportion, and in this way the chief tri-boundary points of all the *internal* circuits of a survey, and the same for

the *external* circuits are duly prepared, as a guide for the compiler of the district or general map, and by means of which co-ordinate Tables, the value of the protractors is greatly enhanced.

These co-ordinates, as well as for all remarkable places and conspicuous objects, are also calculated from one original station or point of departure for the entire survey, to which they are referrible, with the numerical data of any of the grand trigonometrical stations which may exist in the part of the country under survey. It is usual to record this information in a Tabular statement on the pergunnah maps, as shown in Plate X., and likewise to prepare a general Table of the mathematical results of all the main circuit computations, detailing the ratio of error actually met in the angular and linear measurements, the difference between the deduced and observed azimuth, as well as the per centage of error between the areas.

After the area of the figure is thus recorded, by taking half the difference between the sums of the
 Checking. North and South products, another test is applied, by resorting to the Triangulation of the plot, either by reducing the Polygonal figure into one triangle, as shown in Problem 34, page 97, and which is an excellent mode, and the one generally adopted, or by dividing the figure into trapezia and triangles, and so find the area of the whole, by scale and compass. The area by Triangulation should be noted on the Traverse Register Form, so that the difference between the two results, may be seen at one view; the discrepancy will seldom exceed half per cent., and should it be more than one per cent., the product columns must be carefully revised.

Another very expeditious mode of checking these village areas, is by means of the Talc Square, as described in page 267, the squares being divided off into 4 acres instead of one acre each. With a little practice and care in balancing the irregular boundaries, the area of any figure of 500 or 600 acres will

thus be obtained with great nicety, and correspond with the Traverse area within half per cent.

Both the village and the main circuit Traverses are worked out in this way, and the latter comprising 200 villages perhaps, or upwards, the aggregate area of the whole should coincide within one per cent of the summation of the several contained circuits, between station lines, and this forms another admirable check, and tends to place the superficial area of the district on the most accurate possible footing.

Although there is much work to be plotted in the recess, still some portion of it is done during the field
 Plotting. season, as mentioned in Chapter XIII., page 345. The first protraction of the village circuits on the scale of 4 inches to the mile, should be made as soon after the survey is completed as possible, and a good Surveyor, who has his subordinates well in hand, will always have his rough office sheets or *chudders* well brought up, before retiring for the recess. The first thing to be looked to is the entire completion of the chudder map. As soon as the circuit station lines are protracted, according to the method laid down in Chapter VIII., page 287, the boundary offsets have to be applied either from the Field-books, and regularly plotted from the chain distances, or transferred from the rough field maps of the detail Surveyors, (commonly called *péta nâps*), as described at pages 345 to 349. Each Pergunnah or main circuit probably comprises 10 or 12 of these chudders or sheets, covered with a certain number of circuits, and the paper being carefully ruled into squares of 80 chains each, the labor of protraction is greatly diminished in comparison with having to lay down each village on its own separate register sheet, the village boundaries are inserted with a clear well-defined line.

So much of the plotting refers only to the *Village* plans, in addition to which *Pergunnah* plans are required, on a scale of *one inch to the mile*, in the preparation of which the utmost care is required, in laying off the co-ordinates for each triple

boundary, in the first instance on a sheet of drawing paper, duly prepared with squares over its entire surface or co-ordinate lines of 5 inches each, for facility of scale and to obviate the necessity of extending the compasses beyond that length. These lines representing the meridians and perpendiculars of the map, the distances from the main circuit traverses are laid off parallel thereto, and with two pairs of common compasses and a diagonal scale, the circuit may be protracted with great rapidity. One pair of compasses being kept for distances on the meridian, the other for distances on the perpendicular. By reducing the circuit station lines to a few, for the first closing, and thus fixing the salient points in the first instance, the chance of error is greatly diminished, and the intermediate stations may be more truly placed than by any other method, as so truly remarked by Hutton.

In protracting main circuits on the scale of *one inch to the mile*, squares of 5 inches are most convenient, because one inch being equal to 80 chains, each square will represent 400 chains; if a diagonal scale is made on the paper by taking 5 inches from a Gunter's scale, or other standard measure, and dividing it off into 4 equal parts, and the left hand division again into 10 equal parts, each larger division will equal 100 chains and each smaller one 10 chains, on the scale of one inch to 80 chains or one mile. With such a scale it is only necessary, in the plotting columns of the main circuit traverse, to remove the decimal points one place to the left hand and take the distance required off this scale, reckoning each larger division as so many tens of chains, and each smaller one, as units, thus—

Given the co-ordinate distances to be plotted N. 224·80, E. 358·60, remove the decimal point one place to the left hand, and take off the scale N. 22·48, and E. 35·86, which in value will be equal to the former.

When the plot extends beyond the first or second set of squares 40 or 80 must be deducted from the quantity to be

plotted and the balance laid off from the second or third meridian, as the case may be. Thus to protract S. 864.50, and W. 982.40, removing the decimal point will give S. 86.45 and W. 98.24, and deducting 80 from each, there will remain S. 6.45, W. 18.24 to be laid off from the 3rd meridian and perpendicular South and West of the first station in the series. It will thus be seen that correctness of the relative situation of all the station points is entirely dependent on that of the squares, the greatest care must therefore be taken in drawing them. The best instrument for the purpose is a good wooden beam compass, and the squares should be tested by measuring and comparing the diagonals in every way until they are perfect, on attaining which they should be inked in at once, *and never erased from the plan*, and it is a standing departmental rule, that no pergunnah or general map be received in the Surveyor General's Office, without these co-ordinate lines are distinctly defined.

The basis of the map being thus firmly established, the most convenient and prominent intermediate stations are easily perceivable from the 4-inch chudder map. These are then protracted from the traverse data, together with all tri-boundary intersections of adjoining pergunnahs on the 1-inch map commencing at the first station of the survey, and will form ample data, for the purpose of filling in the intervals of the exterior boundary of the pergunnah, which can be performed by pentagraph, reducing the same from the larger scale map. Too many survey *stations* plotted on so small a scale, especially if the lines happen to be short, only tend to confuse the map and prove an impediment to that clear definition of the boundary, which is the chief point to be attended to.

The pergunnah map on the 1-inch, and the village map on the 4-inch scale, form the only returns required of Surveyors, with the exception of an *index sketch* or outline of the several circuits surveyed during the season, which is given on a scale of 4 miles to the inch. This is intended as a mere guide

P.E.X.

to the compiler and explanatory of the annual report. The protraction of the several tri-boundary points is easily performed on this scale from the co-ordinate Tables, and the remainder of the sketch is filled in by the pentagraph. This sketch has no pretensions to accuracy as a permanent record, and is superceded immediately the General Map is compiled in the Surveyor General's Office.

The Great Trigonometrical Survey's principal points are similarly laid off by differences of latitude and departures, as well as all other conspicuous objects, the co-ordinate distances of which have been calculated, and form so many fixed points on which to check the compilation of the materials into the General Atlas.

The whole of the groundwork or basis of the maps having been thus completed, from the materials furnished by the *angular* measurements of the *boundary* Surveyors, the interior topographical items remain to be compiled into the General Map of the Pergunnah. This division of the work we have already shown at page 346, is invariably plotted in the field on the drawing boards as each village details are surveyed. In incorporating them into the *chudder* map, either by pricking or tracing off, the accuracy of the work may be checked by comparing the several points of intersection of rivers, roads, village sites, &c., with the boundary, as produced by the *Theodolite* survey and the same items as brought in by the interior assistant or *prismatic compass* survey. All objects of geographical interest, are of course observed and noted, when within reach of the boundary Surveyor, although not given out on the board with the station lines, and this acts as a check on the other party. Where doubt exists or discrepancies are apparent, it is usual to replot the interior work from the bearings and distances recorded on the *péta nâp*. The whole of this work is neatly inked in on the chudder, which is then ready for transfer to the village register sheets, or reduction for the pergunnah

Compiling and
Drawing.

particular kind, but may, with equal facility, be used for copying figures, plans, sea-charts, maps, profiles, landscapes, &c." If the pergunnah map be so large that it cannot be brought within one setting of the instrument, three or more points, common to the separate sheets of the original plan, must be marked, and made to correspond with the same on the copy. These points serve to fix the Pentagraph towards the interior of the map. The fulcrum and copy may then be removed into such situations as to admit the reducing of the remaining part of the original; first observing that when the tracing point is applied to the three points marked on the original, the pencil falls on the three corresponding points upon the copy, and thus, by repeated shiftings, a Pentagraph may be made to copy an original of ever so large dimensions.

To reduce or enlarge any figure or plan from one scale to another mechanically by means of squares, it is only necessary to divide the original plan by cross-lines into as many squares as may be thought necessary, and then dividing the paper on which the copy is to be made into an equal number of squares, either greater or less, as the case may be. Draw by the hand, or with the help of proportional compasses, in every square, what is contained in the corresponding square of the given figure, and by these means a very exact copy may be obtained.

It is absolutely necessary to show on the 1-inch maps all the village boundaries. The amount of work to be reduced therefore becomes very extensive, the inflections of the boundaries being so extremely tortuous and intricate, and without the Pentagraph the work, on a Revenue Survey, could not well be completed within the time allowed. There are other modes of reducing and enlarging plans laid down in Adams' Essays and other works, which we need not enlarge upon here, but refer the reader to that work, if further information is required.

The process of enlarging drawings is a similar operation to reducing; the points being determined in the smaller squares

of the original and transferred to the larger squares of the copy, or by removing the tracing point and pencil of the Pentagraph as before directed—but the process of *enlarging*, under any circumstances, does not admit of the same accuracy as that of *reducing*, and while the Pentagraph affords the most ample means of reducing a plan, it cannot be recommended for enlarging a copy, or even copying on the same scale. In the Survey of a Town, Civil Station, or Cantonment, which is always required on an enlarged scale, the work must be specially plotted for that scale, and never transferred from a smaller one.

To produce a copy of the same size as the original. Lay the original drawing upon the sheet of paper intended for the copy, and fix them together by means of weights, or drawing pins,* and with a fine needle† prick through all the angles and principal points, so as to make corresponding punctures in the paper beneath. Draw upon the copy such of the lines on the original, as are all straight or nearly so, by joining the points thus marked upon the paper. Set off such other curved lines by means of compasses where necessary, or draw the curves on tracing paper, and transfer them to the copy by means of rubbing the back of the tracing paper with powdered lead, or by rubbing a soft pencil over the lines, then placing it in its correct situation upon the copy, and passing a blunt tracing point over the lines drawn upon it. By means of tracing paper and black leads, and the tracing point, an entire plan may easily be transferred—but the usual method is with a tracing glass which will be found in all Surveyors' Offices. The glass fixed in the wooden frame to elevate or depress at pleasure, is placed in such a position before a window, as to have a strong light falling upon it from behind and shining through it. If the other doors or

* The drawing pin consists of a brass head with a steel point at right angles to its plane.

† The pricking point is described at page 200.

windows in the room are closed, and a curtain hung from the top of the window to rest on the top of the glass, the original drawing becomes distinctly visible through thick drawing paper placed over it, and pinned at the four corners. A copy may thus be made with precision and ease, without any risk of soiling or injuring the original.

The practice on the Revenue Surveys is, when the original Pergunnah map is complete, to trace off the duplicate copy intended for the Local Civil Authorities through the glass, omitting merely the *station lines of the Survey*, which are not required except for professional purposes. For the village map it is necessary to transfer the plan, from a large sheet containing many village circuits, to a single lithographed form, with a statistical Register and area statement heading as shown in Plate VIII. The first copy therefore is generally *pricked off* for the convenience of handling the maps, and when this is complete in every respect, the second or *Collector's copy* is traced off, on a similar lithographed register sheet. The contents of the *chuddur* map are thus taken off piecemeal, village by village, until every circuit is transferred to its Register sheet, on the back of which the traverse proof and area calculation is duly inserted as shown in the specimen plate which is an exact and complete copy of the survey of a village in the North-Western Provinces, and represents precisely the mode of making up and perfecting these records on this side of India. This copying is generally performed by the native assistants, each sheet being very carefully compared and examined with the original, by the assistant who affixes his initials to it.

The skeleton map having been thus completed, and the outlines of all the topographical details carefully drawn *in ink*, the next step is the *colouring*, which may be commenced by laying a broad wash of a light shade of any color along the external edge of the pergunnah, washing off the color gradually towards the interior. This shade can be deepened to the

fancy of the Surveyor by continued coats until the required depth is obtained. Then proceed to color the village sites, rivers, roads and every other item according to the departmental practice as laid down in a list of references (Plate XII.) given elsewhere, and to which it is essential, for the sake of uniformity strictly to adhere. In laying on the color for rivers and other items, the coats should be, in the first instance, very light, and repeated gradually until of sufficient strength, for by these means *softness* and *roundness* is attained, whilst a thick heavy shade laid on all at once, never can produce a proper tone, and looks extremely bad. For water, *Prussian Blue* is invariably to be used instead of *Indigo*, as being of a brighter and clearer color. For very highly finished maps *Cobalt* is very effective, but being an expensive color is seldom used. High roads, metalled, are represented with a strong streak of *Crimson Lake*, (or *Carmine*, which is better) in contra-distinction to village roads and footpaths in *Burnt Sienna*. The exterior edge or limits of the pergunnah or other subdivision is then defined by a dark narrow streak, which throws out the feature into good-relief, but care should be observed in not making this color *too dark*, and thereby confusing the actual line of boundary, and rendering copying or transfer difficult. When several pergunnahs are on one plan, the different shades of color should contrast well with each other, so that each division may be distinctly visible to the eye. Plate X. represents, as well as a lithographed drawing can do, the style of coloring for a pergunnah map, and Plate VIII. for a village map, but no *lithographed* map can equal the style of a good manuscript drawing, and the plates in question are given more to show the form and style of record, than as specimens of topographical drawing. Beginners should first be taught to lay on *flat* shades of color, and to be cautious in not overstepping the edges of the part or item to be covered, and then to wash off a sloping shade and to apply the brush with just as much color in it, as may be wet enough,

not to be absorbed on the paper before the water brush can be applied for softening down, and so prevent what is usually termed a *cut shade*, and which is a great eyesore on any drawing. In executing this description of work, two brushes on the same stick are employed, the color brush on one end, the water brush on the other.

“Of the methods of expressing upon paper the various objects which the face of a country presents, and that are required to be delineated by the topographical draftsman, the drawing of hills demands the most serious attention, it is by far the most difficult art in plan drawing, objects having elevation can only be expressed upon a flat surface, by means of shade or by being thrown into *relief*, the appearance of which can only be given in a ground

NOTE.—In using cake colors, you must dilute them with softwater, observing to mix them intimately together, till the desired tint of color has been obtained, then with a brush in proportion to the size of the space you are going to color, apply the wash steadily and quickly : but do not suffer the proper limits to be passed, nor a greater quantity of color to be used than will evenly cover the space ; as, when too much is used, it is liable to settle in particular places, and, by making deeper tints in one place than another, the work will appear clouded. You should also observe not to allow any two limits of the same color to touch each other, and endeavour to distribute your colors so as to produce a pleasing effect on the whole ; but that taste which quickly perceives excellencies or defects, so as to be soon delighted with the former and disgusted with the latter, must assist you in distinguishing and discriminating the most striking methods of giving this finish to your maps. The water should be colored last, with a very light wash of verdigris, and if it is not very expeditiously laid on, it will be clouded and offensive to the eye. The map should be damped with a clean, moist cloth, laid over it for a few minutes previously to coloring the water. And should you have occasion to color a printed map, the colors may be kept from sinking, by wetting the back of the print with a solution of four ounces of roach alum in a pint of spring water, allowing the paper to dry from the water, before the colors are laid on. This will not only prevent the colors from sinking, but give them an additional beauty and lustre, and preserve them from fading ; and if the paper is not good, wash it three or four times, suffering it to dry between every wash. The printing or lettering the names of places, should be done when the colors on your map are perfectly dry.—*Jameison's Treatise on the Construction of Maps.*

plan, to bodies whose forms present either slopes or curves. A hill representing slopes can be faithfully expressed on a ground plan, so as to convey an idea of elevation to all who are acquainted with the principles of plan drawing, but the chief difficulty lies in so expressing these features as to be enabled to form a judgment of their height when compared with each other, for it cannot be determined by the actual elevation of any single hill.

“The theory, most generally adopted, supposes the light to fall vertically upon the hills in parallel rays. In the projection, the eye is supposed to be at an indefinite distance, and consequently the rays are all parallel, according to which, steep slopes receiving those rays at a more oblique angle, than more gentle ones do, are therefore illuminated in a less degree than the latter, and must be shown on a plan by a darker shade, while such portions of the ground as are horizontal and receive consequently the rays of light perpendicularly to their planes, being thus illuminated in the greatest degree are left without shade in a plan; but as it is scarcely possible to fix a criterion for the depths of tint in shading to express *ground*, it is idle to suppose that, practically, the shading can ever be so exact, as to enable us to measure by it, the positive height of a hill.

“The most rapid way of expressing hills upon paper is by shading with Indian ink or neutral tint. For this, two camel hair brushes are used, one to lay on the tint, the other for softening it down. A dexterous hand will thus speedily dash in, the hills of a plan, a proficient with the brush or pen, will always contrive to throw a certain degree of spirit into his performance, whatever may be the nature of the ground he is representing, but this is the result of much practice, combined with a natural taste for drawing.”*

“The hills should be sketched lightly but carefully on the fair plan, for much evidently depends upon this. It would be

* Jackson's Course of Military Surveying.

fruitless to employ so much time in the field if we did not follow it up to the last. A light tint of Indian ink is to be distributed freely along the tops and most elevated parts of those hills which are the origin of the underfeatures, and softened down into the ravines, with a brush and water, then upon the next series of levels, and so on until the last underfeature has been shaded. Whatever parts still want strength are again to be similarly shaded, beginning a little below the first tint and thus until it is finished. If the ground or any part of it is irregular or rocky, a rougher shading must be disposed upon it, as to the judgment of the draftsman may seem to convey the best idea of such local circumstances.

“There are two methods of describing hills, both in the field and in the drawing room. One called the *vertical*, and the other the *horizontal* style, which are, or rather should be, peculiar to the pencil or pen; for there is no absolute necessity for having recourse to any touches on an Indian ink plan, if the irregularities of surface are properly described by shade.

“In the first method the shade is formed by strokes of the pencil or pen radiating from or converging into any curved part of a hill, according as it projects or re-enters:—they are supposed to describe the same course as water would do, if it could trickle in streams down the slopes, and are darker or lighter according to the steepness of the slope.

“The other method has the shade formed by lines parallel, or nearly so to the horizon. It is much more easy to apply, and more natural than the former and has some claim to particular notice from its easy application in sketching and the facility with which it may be demonstrated and acquired.”* The *horizontal* manner marks the Contours of hills by waving lines, each line continuing on the same level while following every undulation of the ground. In practice, either or both of the styles may be used at the pleasure of the draftsman, or as may

* Treatise on Practical Surveying and Topographical Plan Drawing.

be best suited to the nature of the ground he wishes to portray.

“ The rays of light being supposed to fall vertically upon the ground, the degree of shade, used for expressing hills, depends on the greater or less gradations of their declivities, that is, the more the slope of a hill recedes, from the horizontal, the darker must be the shade. Although this principle may be considered as generally the best, yet in making a finished plan of any mountainous region, an artist should not be confined too rigorously in this respect, for a clever draftsman would then like to throw his mountains in what is termed *light* and *shade*; which supposes the rays of light to come on the plan from the left upper corner; according to which supposition, one side of a hill becomes brightly illuminated, while its reverse is cast into deep shadow. Attempts have been made to have the oblique light system generally adopted, but it is not suited to express *tame ground*. A kind of compromise therefore subsists; thus, we make the rays of light to fall vertically *upon the hills*, while all other objects, as rivers, houses, trees, &c., receive it obliquely. This may appear absurd, but where all is conventional, the contradiction is not felt as an inconvenience; generally speaking, the object of giving shadow to houses, rivers, &c., is chiefly as a finish, and for effect.”* Almost universally the shades used by draftsmen are too dark; and in India especially, the subject does not receive the attention it demands, and we commend to the especial observance of Revenue Surveyors, the remarks from an able authority quoted in the foot note.† The “ *Caterpillars*” therein alluded

* Jackson’s Course of Military Surveying.

† The difficulty which involves the representation of all the inequalities of the proposed portion of the earth’s surface, and consequently the features of a mountainous country has been variously got over. In the very old maps, a congregation of conventional signs, each intended to represent a mountain, was introduced and arranged so as to give some idea of the direction in which the mountain land was disposed. Those who have seen maps, executed on

to, are too common in the present day, and from the extensive employment of native draftsmen, the topographical drawings now produced answer most completely to this description. This must be the case, as long as Officers in charge of surveys, delegate such duties to mere mechanical and ignorant copyists, who know no more of the principles which should guide them in the representation of *ground* than the brush, by the aid of which they annually destroy so much paper. The hilly features should invariably be put in, *by the Surveyor* himself after a careful study of the ground, and without this personal examination in the Field, it must be vain to attempt to give even an approximation to the truth. It is evident that a map, to be anything, ought to be precise; it is otherwise worse than useless.

On the style and character of the *Printing* of a map depends its general appearance, as well as degree of usefulness. The most elaborate topographical drawing will be nothing, unless the names of the

this principle, will acknowledge how very imperfect is the information it gives of the inequalities of the ground, either as to arrangement and connection or elevation above the general *plateau* of the country. Rude as the method is, and destitute of precise meaning, I have known many who affected to prefer it to the modern method of *deep notching*, which they assert has the effect of rendering a map illegible, without being a whit more precise. There is some ground, it must be confessed, for forming this opinion, at least if we confine ourselves to English maps; but those executed on the continent do not deserve this censure. Arrowsmith's map of India is a splendid example of this cheatery of the eye. To form any thing like a correct idea of the surface of India from this map, thickly as it is covered in parts with these "*caterpillars*," as I have heard them called, is impossible. Very often, it will be found, that what the peruser of the map supposes is a high ridge, is in reality a low one and *vice versâ*, while valleys are elevated into ridges and these again sunk to valleys. A certain quantity of ink has been applied to the paper but to what purpose, save that of blackening it, it would puzzle Odipus himself to say. Nor are the maps of other publishers much better, and still more extraordinary I fear, that even to many *manuscript maps executed in this country much of this censure must attach*. Gleanings in Science, volume 2nd, 1830, "*On the different methods of shading mountain land, by Delta.*"

places, title, and other embellishments are recorded in a corresponding manner, with due regard to effect, combined with practical utility. Generally speaking, this is the most difficult part of a map to *do well*, and there are many persons who can color and draw in a superior manner, but who fail in printing, for this reason the attainments of each assistant on a Survey Establishment should be well ascertained in making arrangements for the distribution of the work, and the division of labor. The first principle to be observed in printing, is that each class of names should be represented by one uniform character. Thus erect capitals are used for capital places of the first order. Italic or sloping capitals for places next in order, with 1,000 houses. Erect small letters with capital prefixed, commonly called *roman* writing, for large villages, containing one thousand inhabitants and upwards, or about 250 houses, and other remarkable or conspicuous objects, and small italic writing for common villages under 250 houses or one thousand inhabitants.

The great mass of printing on the body of the drawing of a map, should invariably be parallel to the top and bottom edges of the paper, and it is usual to place the first letter of the name as close to the site as it is possible to be. In addition to this it is generally requisite to have curved lines of printing in certain situations, for the names of adjoining districts or *pergunnahs*, and when judiciously applied materially adds to the beauty of the map. In the curved or contorted external boundary of the *pergunnahs* or divisions represented in the map, the names of the adjoining divisions should be so disposed as to run as nearly parallel to the general outline as possible, and when several *pergunnahs* or subdivisions are exhibited on the same plan, the name requires to be stretched across the space with the letters at *equal intervals*, to show the extent or connexion of the same.

On winding rivers, roads, lakes, coasts, &c., the writing must be curved to correspond with the thing represented, and the
























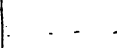










general appearance of all the names and writing should invariably be to face the *north end* or *top* of the paper, so that it may be all legible at one view, by placing the map before you and not upside down, requiring the plan to be shifted, before it can be read.

In very extensive *Titles*, it is also necessary sometimes to insert curved lines, to take off from the monotonous appearance of a number of straight lines,* but as a general rule we deprecate *fancy hieroglyphics* and elaborately devised printing which may be difficult to read; plainness and neatness, tends to general utility, and is moreover a great saving of time, and in a large department where one uniform practice is so important, it is obviously preferable to follow a style, which the majority of draftsmen can most easily attain, and adapt to the work entrusted to them.

For this reason the *stone* or *Egyptian* letter is employed, for all names of *Pergunnahs*, whether on the body of the drawing, as adjoining name, or in the *title*. This style of printing being extremely easy to make, while it looks substantial and plain, and catches the eye; for the *District* names, whether adjoining, or title, the open or *ornamented stone* letters filled with a little color, Indian ink or neutral tint a little larger than the Pergunnah character, are found sufficiently contrasting and distinguishable. These styles are shown in Plate XII. on the list of topographical items, or conventional signs, which now guide the department. A very extensive use of symbolic writing on a map may be confusing, but its partial application is not without its advantages in the way of significance.

* Curves may be best formed by one person holding a steel or other elastic ruler into the form desired, and placing it with its edge on the paper alongside the crooked boundary. The elastic ruler must be held in this position while another person rules or marks with a pencil along it. In this way curves of all shapes may be formed with the greatest ease, and possessing a grace and elegance which is scarcely attainable by any other means.

TOPOGRAPHICAL ITEMS

1	City or Town.....		18	Thannah.....	
2	Village.....		19	Police Chowkey.....	
3	Haut or Bazar.....		20	Signal Staff.....	
4	Pucka Fort.....		21	Light House.....	
5	Mud Fort.....		22	Pucka Semaphore or Telegraph.....	
6	Pucka Houses.....		23	Boundary or Rev. Survey Pillar.....	
7	Pagoda or Hindoo Temple.....		24	D°... Wooden Post.....	
8	Musjid or Mahomedan Temple.....		25	Principal Stations of the G.T.S.....	
9	Salt Golahs.....		26	Secondary... D°... D°.....	
10	Dak Bungalow.....		27	High Road.....	
11	Indigo Factory.....		28	Village D°.....	
12	Silk... D°.....		29	Foot Path.....	
13	Sugar D°.....		30	Rail Road.....	
14	Burial Ground.....		31	Bunds.....	
15	Pucka Wall.....		32	Bridge Pucka.....	
16	Kucha D°.....		33	... D°... Wooden.....	
17	Dep ^t Mag ^t and Moonsiff's Kutcherry.....		34	Sluice Gate.....	

List of Colors, used in these Items.

Indian Ink. Prussian Blue. Lake. Light Red. B^t

Sienna. and Gamboge.

Umber is made from B^t Sienna and Indian Ink.

Ochre... D°... D^t... Light Red and Gamboge.

Green... D°... D^t... Prussian blue and... D°.....

Large Towns thus..

2000 Houses..... } **LIMBAE**

Stone Capitals

Smaller or Pst

Towns from 1000

to 2000 Houses.. } **RENCHO**

Italic Capitals

Noted Places and

Villages from 250

to 1000 Houses... } **HOMMURHAUT**

Romans





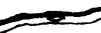


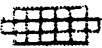


















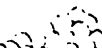

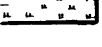
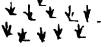


Villages under 250

Houses. } **BUSTUNPOOR**

Small print

Digitized by

TOPOGRAPHICAL ITEMS

55	<i>Iron Suspension Bridge</i>		52	<i>Waste or Grazing Ground.</i>	
56	<i>Nudges</i>		53	<i>Salt Waste</i>	
57	<i>Ferry</i>		54	<i>D^o with Jungle intermixed.</i>	
58	<i>River</i>		55	<i>Salt Pans.</i>	
59	<i>Pawn Garden</i>		56	<i>Barrines</i>	
60	<i>Garden</i>		57	<i>Thael</i>	
61	<i>Mangoe Tops</i>		58	<i>Lake or Tank</i>	
62	<i>Tamarind Trees</i>		59	<i>Chur or Sand bed</i>	
63	<i>Palmyra or Tar Trees</i>		60	<i>High Ground</i>	
64	<i>Cocanut Trees</i>		61	<i>Sand Hills</i>	
65	<i>Date D^o</i>		62	<i>Hills Ridge with Peaks</i>	
66	<i>Betal Nut D^o</i>		63	<i>Ridge</i>	
67	<i>Bamboo Jungle</i>		<u>For Village Plans.</u>		
68	<i>Forest D^o</i>		64	<i>Cultivation</i>	
69	<i>Low D^o</i>		65	<i>Lately thrown out of cultivation</i>	
70	<i>Thow D^o</i>		66	<i>Fit for Cultivation</i>	
71	<i>Grass D^o</i>				

Style for Purgunnah, Title,

or Adjoining Names.....

KOTRANG

Style for District, Title

or Adjoining Names.....

CUTTACK

“ The characters used for printing the names of places and things represented on maps, should bear such proportion as the relative importance of the objects bear to each other. The *title* should be proportionate to the size of the map, and the adjoining names, according to the distribution of the spaces to be filled up, so that the whole may present one uniform appearance. Every thing ought to harmonize, for whatever obtrudes itself too much on the attention, without some good reason for so doing, may be said to be out of place; nothing looks so bad as a great daub of a title, with ornamental letters and flourishes, on a small and unpretending plan.”* Thus the word *Pergunnah* should not be so prominent as its distinguishing name, and the word *District* as the name of that district which is the point required to be seen; we have endeavoured to exemplify these matters on the Pergunnah map of Limbae, Plate X., which is prepared in strict conformity with the standing departmental rules laid down for the guidance of all Surveyors as far as the present state of the Lithographic art in Calcutta will permit.

The titles, or headings for the village plans, are generally written in a neat round text, *vide* Plates VIII. and IX. The immense number of these plans which require to be completed during the season, prevents a more laborious style of printing, and which indeed is not necessary for the description of record, the adjoining names on these latter maps are also recorded in neat round handwriting, as shewn on Plate VIII.

In summing up the several steps before adverted to, it is necessary to make a few remarks on plan drawing generally, which may be divided into *Topographical* and *Geographical* plans.

A *Topographical* plan should represent the detail, and contain all that is necessary towards acquiring a special knowledge of a certain extent of ground, or of a small country or

* “ Hand Book for Plain and Ornamental Mapping, by Benjamin Wilme.”

district, and especially, if for military purposes, for which all plans are more or less intended, such a particular distinction of things and circumstances cannot be attained in geographical maps, which include an extensive portion of the surface of the earth, whole countries and even sometimes the entire globe itself. Topographical maps are made on a larger scale than geographical ones; *one inch to a mile*, although a small scale for such maps is a very proper and convenient one, and is the same on which the Ordnance Survey of England is published. It is also the best for the *Pergunnah* maps of the revenue survey of India, and the smallest scale capable of showing congregated village boundaries in Bengal. *Six inches to one mile*, is a large scale for the survey of a country, and is the one employed for the plans of the Ordnance Survey of Ireland. *Two miles to an inch* is a very useful scale for general district maps to show the fiscal and judicial divisions, places of importance, factories, thannahs, &c. forming sheets of moderate size, and convenient for the local authorities to carry about with them, when on circuit duty. In the North-Western Provinces, this scale is sufficient to show village boundaries, the average area of these circuits being upwards of a square mile, or from 700 to 800 acres each, but in Bengal the villages are so small, averaging not above 300 to 350 acres each, that these boundaries cannot be inserted, on this scale. Four miles to an inch is the scale generally used for *geographical* maps, and is well suited for obtaining a general view of an entire country, and the relative situation of its parts. The sheets of the great Indian Atlas are prepared on this scale as well as all the *District* compilations from the revenue survey *Pergunnah* maps. By means of maps and plans alone, can a complete practical intimacy with the various parts of a country, and of the face and nature of the ground that composes it, be obtained, and they should therefore afford an accurate view of every local object, and furnish a clear, lively and imposing representation of the reality.

The art of drawing maps and plans consists therefore in representing larger or smaller portions of the surface of the earth on paper, in such a manner that every delineation shall bear as strict a resemblance as possible to the natural object, and the entire skill required, is the attainment of a certain facility of manipulation in putting together the materials collected so as to form a map.*

The following remarks from Jackson's Surveying, may be quoted with advantage :

“ A good plan conveys to the mind a more perfect image than can be obtained by looking at the ground itself. It enables us to examine and compare the great features of a country; we trace on it the directions of lines-of coasts, rivers, mountains, woods, forests, &c., distance is nothing, we see the country, twenty, fifty and a hundred miles off, we can estimate the comparative heights of hills, without having to bear in mind, that the angle subtended by a mountain varies with its distance from the eye, or that such an art as perspective exists, nay more, it may be asserted that a really good plan is fully equal, I had almost said, superior for Military purposes to the best model.”

“ In plans there are three things to be desired; 1st, *correctness*, without which a plan is worse than useless; 2nd, *clearness*, in order that every part may be understood; and 3rdly, *beauty of execution*, which is generally found to accompany the second of these desiderata. This last, however, being the only point upon which the majority of persons are capable, or rather

* “ The object of every map may be stated to be a representation on a flat surface, of a portion of the earth, on which all the lines or distances shall as far as the difference of the surface will permit, bear the same proportion to one another as those in nature do. Accuracy is of course essential to it; but the value of the accuracy is like that of other things, comparative, and is always to be judged of by the cost of its production. Perfect mathematical accuracy is as unattainable as it would be useless, *but that degree of it which is likely to be practically useful, is fortunately within our reach.*”—On the Principles of Geodesy, by Delta, Gleanings in Science, vol. 2.

fancy themselves so, of giving an opinion, naturally excites their chief attention.

“When examining a plan how rarely do we think of the labor with which it has been produced, the triangulation to obtain certain points as land marks, the arduous business of surveying every yard of road or stream, the ability and care necessary when sketching the forms of the ground, and the minute attention required for innumerable minor details; how seldom do all, or any of these considerations enter into our thoughts, when a plan is shown to us; and yet the merit, which attaches to the mere drawing, the language, as it may be termed, of the Surveyor, an accomplishment little more than mechanical, is trifling indeed, when compared with the degree of talent and labor employed in the formation of a good plan. Perhaps *time* may afford some criterion, whereby to judge of the comparative value of *plan drawing* and *plan making*. An expert draftsman will in the space of two or three days, produce a copy of a plan, the field labor and plotting of which may have employed a Surveyor for a whole year.”

The “practical hints,” in the foot-notes extracted from Simms’ Treatise on Drawing Instruments, will be found useful.* We have likewise added a receipt for restoring

* *Practical Hints, &c., on the Management of Drawing Paper.*

The first thing to be done preparatory to the commencement of a drawing is to stretch the paper evenly upon the smooth and flat surface of a drawing board. The edges of the paper should first be cut straight, and, as nearly as possible, at right angles with each other; also the sheets should be so much larger than the intended drawing and its margin, so as to admit of being afterwards cut from the board, leaving the border by which it is attached thereto by glue or paste, as we shall next explain.

The paper must first be thoroughly and equally damped with a sponge and clean water, on the opposite side from that on which the drawing is to be made. When the paper absorbs the water, which may be seen by the wetted side becoming dim, as its surface is viewed slantwise against the light, it is to be laid on the drawing board with the wetted side downwards, and placed so that its edges may be nearly parallel with those of the board; otherwise, in

damaged drawing paper, which in this country so soon becomes affected by the dampness of the atmosphere. Drawing paper should always be wrapped in flannel, and kept

using a T square, an inconvenience may be experienced. This done, lay a straight flat ruler on the paper, with its edge parallel to, and about half an inch from, one of its edges. The ruler must now be held firm, while the said projecting half inch of paper is turned up along its edge ; then, a piece of solid glue (common glue will answer the purpose,) having its edge partially dissolved by holding it in boiling water for a few seconds, must be passed once or twice along the turned edge of the paper, after which, this glued border must be again laid flat by sliding the rule over it, and, the ruler being pressed down upon it, the edge of the paper will adhere to the board. If sufficient glue has been applied, the ruler may be removed directly, and the edge finally rubbed down by an ivory book-knife, or any clean polished substance at hand, which will then firmly cement the paper to the board. Another, but adjoining edge of the paper must, next, be acted upon in like manner, and then the remaining edges in succession ; we say the adjoining edges, because we have occasionally observed that, when the opposite and parallel edges have been laid down first, without continuing the process progressively round the board, a greater degree of care is required to prevent undulations in the paper as it dries.

Sometimes strong paste is used instead of glue ; but, as this takes a longer time to set, it is usual to wet the paper also on the upper surface to within an inch of the paste mark, care being taken not to rub or injure the surface in the process. The wetting of the paper, in either case, is for the purpose of expanding it ; and the edges, being fixed to the board in its enlarged state, act as stretchers upon the paper, while it contracts in drying, which it should be allowed to do gradually. All creases or undulations by this means disappear from the surface, and forms a smooth plane to receive the drawing.

Table of dimensions of drawing paper. Calcutta Price.

				Rs.	As.
Demy,	...	...	20 inches by 15 $\frac{1}{2}$ inches,		3
Medium,	...	...	22 $\frac{3}{4}$ " 17 $\frac{1}{4}$ "		6
Royal,	...	...	24 " 19 $\frac{1}{4}$ "		8
Super Royal,	...	...	27 $\frac{1}{4}$ " 19 $\frac{1}{4}$ "		8
Imperial,	...	...	30 " 22 " "		12
Elephant,	...	...	28 " 23 " "		12
Columbier,	...	...	35 " 23 $\frac{1}{2}$ " "	1	0
Atlas,	...	...	34 " 26 " "	1	0
Double Elephant,	...	...	40 " 27 " "	1	8
Antiquarian,	...	...	53 " 31 " "	4	0
Emperor,	...	...	68 " 48 " "		

closed up in a tin case, and placed well off the ground, and may occasionally be put into an oven and well heated, with advantage.

Mounting paper and drawings, varnishing, &c.

In mounting paper upon canvas, the latter should be well stretched upon a smooth flat surface, being damped for that purpose, and its edges glued down as was recommended in stretching drawing paper. Then, with a brush, spread strong paste upon the canvas, beating it in till the grain of the canvas be all filled up; for this when dry, will prevent the canvas from shrinking when subsequently removed; and having cut the edges of the paper straight, paste one side of every sheet, and lay them upon the canvas, sheet by sheet, overlapping each other a small quantity. If the drawing paper is strong, it is best to let every sheet lie five or six minutes after the paste is put on it; for, as the paste soaks in, the paper will stretch, and may be better spread smooth upon the canvas; whereas, if it be laid on before the paste has moistened the paper, it will stretch afterwards and rise in blisters when laid upon the canvas. The paper should not be cut off from its extended position till thoroughly dry; and the drying should not be hastened, but gradually take place in a dry room, if time permit; if not, the paper may be exposed to the sun, unless in the winter season, when the help of a fire is necessary, care being had that it is not placed too near a scorching heat.

In joining two sheets of paper together, by overlapping, it is necessary, in order to make a neat joint, to feather edge each sheet; this is done by carefully cutting with a knife, half-way through the paper near the edges, and on the sides, which are to overlap each other; then strip off a feather edged slip from each, which being done dexterously, the edges will form a very neat and efficient joint when put together.

The following method of mounting and varnishing drawings or prints was communicated some years ago by Mr. Peacock, an artist of Dublin. Stretch a piece of linen on a frame, to which give a coat of isinglass or common size. Paste the back of the drawing, leave it to soak, and then lay it on the linen. When dry, give it at least four coats of well-made isinglass size, allowing it to dry between each coat. Take Canada balsam, diluted with the best oil of turpentine, and with a clean brush give it a full flowing coat.

In selecting black lead pencils for use, it may be remarked that they ought not to be very soft, nor so hard that their traces cannot be easily erased by the India rubber. Great care should be taken, in the pencilling, that an accurate outline be drawn, the pencil marks should be distinct, yet not heavy, and the use of the rubber should be avoided as much as possible, for its frequent application ruffles the surface of the paper, and will destroy the good effect of shading or colouring, if any is afterwards to be applied.

All copies of either maps, or computations, are duly compared with the original, by two persons who affix their initials to the documents as having done so, and are strictly responsible for the same. The two copies of the village plans, taken from the rough sheets, are first compared with the original and then with each other, and any discrepancy immediately corrected by an European Assistant and not left for future adjustment, perhaps to be forgotten. The boundary of each village is rigorously compared with the *thakbust* or demarcation sketch map, as soon after survey as possible, and it is necessary to record on every map that this step has been taken, and that the assimilation is sufficiently good to allow of its being passed. In case a *khusras*, or detailed measurement field by field, has been made, the map produced by this operation is also duly compared with the professional one, and the agreement of the two is another proof of the work, all discrepancies ensuring an immediate enquiry and reconciliation. In like manner all the traverse computations are compared, one assistant reading from the copy, and the other looking at the original. As soon as these precautions have been taken and the attesting initials of the assistants in charge of the division affixed, the document is ready for the examination of the Superintending Officer, who adds his sig-

Receipt for restoring damaged drawing paper.

Take a wash, composed of one drachm of Isinglass steeped in 2 ounces of water for 12 hours. Then simmer it for 15 or 20 minutes over a fire. When nearly ready add of common alum (fitcooree) in powder 20 grains, strain through linen for use, apply it when the paper is on the drawing board, and damp, and work it on, with a flat brush, when dry, wash the paper over with water, which will indicate whether a second wash of the above is necessary. When the paper is thoroughly recovered, wash it well with plain water, and a flat brush, to take off any superfluous Isinglass, absorbing the superfluous water with a clean linen rag. When thus prepared, the colors can be thrown in, as safely as on good paper.

Captain Henderson's Essay No. 4, on the Pictorial Art.—*Calcutta Literary Gazette*, July 1834.

nature as soon as he is perfectly satisfied of the accuracy and sufficiency of the work, and it is by the exercise of his general knowledge and careful eye, in the detection of errors and omissions, that the value of the results of the survey mainly depend. The amount of information embodied in the 1-inch topographical maps from the larger scale requires careful scrutiny, every thing should be put in, which the scale permits, and these maps forming the chief practical test of a Surveyor's labors as applied to the widest extent of usefulness, no pains should be spared in their examination.

The register sheets for the village plans are lithographed and supplied with a view of lessening the labors of a Surveyor, the statistical and area columns are filled in, the former from the *khusrah* vernacular returns, and the latter from the professional computations as shown in Plate VIII. The statistics and general remarks of the condition, and state of prosperity of each village are of great importance, and should be recorded by the Surveyor himself. The information thus given, forming the basis of the general statistical and agricultural report of the district. The references to the Settlement Officer's missil, or file of proceedings, enables that Officer to make up his own registers with facility. The duplicate copy of the professional plan register intended for the Civil Authorities is left blank at the back, the numerical data of the survey operations being only required for professional purposes in the Deputy Surveyor General's Office. The back of this register being ruled, all the revenue information, as to names of mehals and proprietors, is inserted on it by the Settlement Officer from the vernacular records of his own proceedings. Every village in the entire district being thus prepared, the detail of information is as complete as can be desired. Plate IX. represents the form of Register for Bengal, or settled Provinces, the Plan and Traverse computation being recorded precisely similar as shewn in Plate VIII.

Filling in Village
Plan Registers.

Village of Roypoor.

গাম রাজপুর

Muhul Roypoor.

মহুল রাজপুর

Purgunnah Balleah.

পূর্ণান বালিহ

DISTRICT 2A PURGUNNAHS.

জেলা চব্বিশ পরগনা

Area by Professional Survey		A	R	P	General Remarks.
No. in Block	Add. Lands of this Village in	1387	3	09	
38%	Chuck Roypoor. Total. N ^o . 83.				This village has three proprietors and 373 Inhabitants of which 265 are Hindoos and 108 Mussulmen. $\frac{1}{2}$ ths of the village is cultivated, $\frac{1}{2}$ th the Khanabaree and $\frac{1}{2}$ th waste land. There are three qualities of soil, and the average rates per begah for cultivation are $\frac{1}{2}$, $\frac{1}{2}$ and $\frac{1}{2}$ respectively and for Khanabaree $\frac{1}{2}$.
32	Budze Kalkemuggur. N ^o . 3.				
37	Chuck Nobausan. N ^o . 21.				
83	Santoshbawtee. N ^o . 32.	63	0	14	
Total Area by Professional Survey		1450	3	23	Total Area by Husrath Measurement or Local Begahs 4117
Deduct lands of other villages as detailed below		3	2		
Recorded Area of Roypoor.		1447	1	23	Ploughs Houses Pucka. Kucha 6 615
or Local Begahs. 4377					
Deduct in this Village Lands belonging to					Scale { 20 Gunter's Chains } to the Inch. or $\frac{1}{2}$ of a Mile
Mundarpoor		3	2		
Total to be deducted.		3	2		The Local Begah Contains 1600 Square Yards Surveyed in January 1847 N ^o of Missil furnished by Civil Superintendent 83 N ^o of Mouzas in Civil Superintendent's list 1

It remains to assort and arrange all the village plans and registers into moderate sized pergunnah volumes, for convenience of record. The Plans may be bound up either alphabetically, according to the English or Persian alphabet, or by means of the geographical position of the village. Every plan is duly numbered and placed in regular succession and from 150 to 200 may be said to form a convenient volume. If a pergunnah is very large, it is of course divided into two or more books as may be necessary, and if very small, two or more pergunnahs are combined together. An alphabetical list of all the villages is prefixed to the volume, containing also columns for the number on the plan as well as the areas, which, summed up, show the correct area of the entire pergunnah. By a reference to this Index List, any plan is immediately found by its number; it is therefore immaterial how the plans are placed, as long as they are numbered properly in succession, and that the Index names of villages, critically accord with the same on the plan sheets. On opening the book, the plan should first be seen, and then the traverse on the reverse side. A list of topographical references to the coloring is invariably appended and saves much labor, which would accrue from recording such items on every plan. A title page with the name of the pergunnah and a few blank sheets of paper are added, for the purpose of inserting any information afterwards, connected with the Survey operations of the pergunnah or district, or as to the geographical features of the country. On the Revenue Surveys these volumes in fact represent the Field-books, as well as the completed work, they should therefore be made to contain every possible information, and be complete in every respect, so as to supercede the demand for Field-books after a Survey is over. So much of the Field measurements being recorded on drawing boards and all plotted at the moment of Survey, the Field-books, according to the usual style of that document, are more

or less partial and imperfect, and therefore not desirable records.

It is next to impossible to lay down absolute and distinct rules for the performance of detail duties.

Division of Labor. As before stated in Chapter XII. every Surveyor may have his own peculiar method of carrying out his work, and in such matters they will be the best judges of the nature of the work they have to perform and of the best means of completing it, all that we advocate is *system* in all that is done, and whatever that method may be, after it has been once maturely considered and definitely determined on, it should not be departed from. Let a Surveyor apportion out to each assistant the particular duty for which he is most qualified, and insist on its being followed. As a general rule each assistant is responsible for the division he has had charge of in the Field, and is expected to bring up the whole of the work connected with it, but it frequently happens that from local causes, one party may accomplish more Field work than they can get out of hand prior to the commencement of another season, whilst another party may not be so pressed for time in the recess, such additional aid and assistance therefore as can be spared, should be afforded where it is most needed. Each assistant has generally five Native Surveyors of various degrees of qualifications under him. One may color well, another may print well, and so on. One man may be employed simply in pricking and tracing off, and pencilling in the village plans. These are made over to a second person, to ink in, to a third to be colored, and to a fourth to have station points, letters and lines entered, and lastly on to a fifth to write and print adjoining names; such a party can complete from fifteen to twenty village maps daily.

By this arrangement the Sub-Assistant is enabled to devote himself chiefly to the more important points in finishing the pergunnah maps and areas, and the Superintending Officer in

exercising a general control over the whole work, taking care that it progresses through every step to his satisfaction, *methodically, cleanly, and accurately*; encouraging *and helping* in all difficulties, and by putting the finishing touches to the plans render them worthy of his professional reputation.

By the means we have here endeavoured to describe, a Surveyor may have the satisfaction of seeing his office cleared by the termination of the recess, and find himself in a position to take the Field again with renewed vigor, unembarrassed by any arrears.

CHAPTER XXVI.

ON THE METHOD OF DESCRIBING THE GRATICULE OF MAPS.

FOR the purpose of representing more accurately the globe which we inhabit, geographers have had recourse to spherical balls, on the surface of which are drawn the various divisions of the earth, but the relative divisions of the earth, and the positions of places, cannot be accurately laid down on these spheres, till certain circles have been described on its surface. These circles are divided into *great* and *small*, and the manner in which they are formed may be described as follows. Imagine a sphere to be cut in any direction by a plane, the section will be a circle. It would be a great circle if the cutting plane passed through the centre of the sphere, and a small circle, if it (the cutting plane) passed out of that centre.

From the manner in which a great and small circle are generated, it is evident that the former will bisect the sphere, while the latter will make an unequal division of it.

The earth turns round once in 24 hours, on an imaginary axis, passing through its centre; the two extremities of this axis, are its poles, the one being called the *North* and the other the *South Pole*. This being apprehended, conceive now the terrestrial sphere to be cut by a certain number of planes perpendicular to the rotatory axis, the sections will obviously be parallel to each other; that passing through the centre of the sphere (a great circle) being called the equator, or the equinoctial line, while all the others

Of the Axis and Poles.

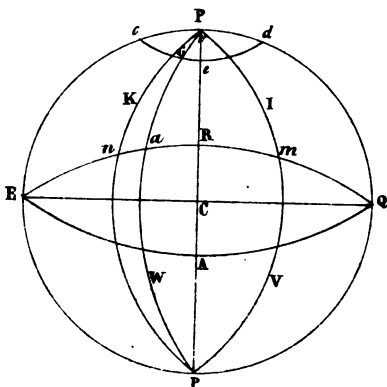
(small circles) are styled the parallels of latitude, or simply parallels.

Again a point being assumed on the terrestrial globe, the cutting plane may be imagined to pass through it, and the axis of rotation, the section (a great circle) will be the meridian of that point, being perpendicular to the equator, and to the parallels, and passing through the North and South Poles.

The latitude and longitude of a place may be defined in the following manner. The meridian to the given place being drawn in the way above described, the section thereof intercepted between the equator and the given point is called the *latitude*, which will be North or South, according as the meridional section, which is its measure, extends towards the North or South Pole. The *longitude* is reckoned upon the equator commencing from a point arbitrarily assumed as the origin, and continued as far as its intersection with the meridian of the given place. In English works on geography the meeting of the equator with the meridian of the Greenwich observatory, is taken as the origin of the longitudinal arc which is measured both ways, viz. to the East and West of that meridian.

“By way of illustrating the foregoing definition of latitude and longitude let us suppose that $PEP'Q$ in adjoining diagram represents the earth,

whose axis is PCP' ; the North Pole P , and the South Pole P' ; and let $EAQR$ represent a circle passing through the centre C , in a direction perpendicular to the axis PP' . This circle corresponds to the equator, and it



divides the earth into two hemispheres; EPQ being the Northern, and $EP'Q$ the Southern hemisphere.

“ Let G, I, K , represent the situation of three places, on the surface of the earth, through which, let the great circles $PKP', PIP',$ and PGP' be drawn, intersecting the equator EQ , in n, m, a , respectively.

“ These circles are the meridians of the places K, I, G , and as every circle is supposed to be divided into 360° there must be 90° from the equator to each pole. Hence the latitude of the place K is measured by the degrees of the arc intercepted between K and n ; and the latitudes of G and I are measured by the degrees of the arc intercepted between G and a , and I and m , respectively. These latitudes will be called North latitudes, because the places lie in the Northern hemisphere.

“ In like manner, let there be two places W and V in the Southern hemisphere. The latitude of W will be measured by the degrees of the arc intercepted between W and a , and the latitude of V , by the arc intercepted between V and m , and these will be called South latitudes. The distance between I and V is called the difference of latitude.

“ The longitude of a place is measured by the degrees of an arc of the equator, intercepted between some particular meridian, and the meridian passing through the place. Thus suppose G

to represent the particular meridian and m to represent the place whose longitude is required; the longitude of m is measured by the arc ma of the equator, intercepted between a and the point where the meridian of G meets the equator, and m the point of the equator where it is cut by the meridian of the place m . The particular meridian, from which we begin to reckon the degrees of longitude, is called the *prime* or *first meridian*, and it is different in different countries.

“ In the foregoing diagram if G represent the observatory of Greenwich, a will be the point from which we begin to

Illustration of Longitude.

reckon the degrees of longitude; and all places situated to the East of a , such as R, m , will have East longitude, while those situated to the West, as n , will have West longitude. Longitude is usually reckoned 180° East and West of the prime or first meridian. For instance, taking a as the prime meridian and reckoning in the direction R, m, Q , we should say, that every place was so many degrees East *Longitude*, while if we reckoned in the direction n, E , we should say, all the places had so many degrees West longitude.* From a consideration of what has been advanced it will be evident that all places situated upon the same meridian have the same *Longitude*, while all those situated upon the same parallel have the same *Latitude*, again as the parallels of latitude become smaller as they approach the poles, the arcs of these parallels intercepted between the same two meridians, will also be smaller as we proceed from the equator to the poles, though in fact they consist of the same absolute number of degrees. Hence it will be easy to see, that a degree of longitude, must be smaller towards the poles, than at the equator; and must become gradually smaller and smaller till we arrive at the poles, where it will vanish and be equal to nothing.

We have hitherto supposed the earth to be a sphere, but its real figure is a spheroid, the minor axis of which being the axis of rotation. If therefore the several lines whereby latitudes and longitudes are measured, are described upon a spheroid, in the same manner, as has been done upon a sphere, it will be seen that while the equator and the parallels are circles, the meridians are ellipses, equal and similar to one another whose degrees vary in length in different latitudes. The following Tables exhibit the linear values of the degrees upon the meridian and the parallels from 8° to 36° North latitude, the extreme limits of our Indian possessions computed upon the spheroidal hypothesis.

* Jamieson's Treatise on Construction of Maps.

Table exhibiting the Lengths of the Meridional Degrees between the parallels of 8° and 36° of Latitude.				Table exhibiting the values of the Longitudinal Degrees between the parallels of 8° and 36° of Latitude.			
Latitude.	Meridional Degrees in Miles.	Latitude.	Meridional Degrees in Miles.	Latitude.	Value of one Longitudinal Degree.	Latitude.	Value of one Longitudinal Degree.
					Miles.		Miles.
° °		° °		°		°	
8 to 9	68-718	23 to 23	68-903	8	68-463	23	63-066
9 to 10	68-721	23 to 24	68-812	9	68-316	24	63-217
10 to 11	68-725	24 to 25	68-820	10	68-118	25	62-719
11 to 12	68-730	25 to 26	68-830	11	67-899	26	62-202
12 to 13	68-735	26 to 27	68-839	12	67-660	27	61-666
13 to 14	68-740	27 to 28	68-849	13	67-400	28	61-111
14 to 15	68-746	28 to 29	68-859	14	67-120	29	60-539
15 to 16	68-752	29 to 30	68-869	15	66-820	30	59-946
16 to 17	68-758	30 to 31	68-879	16	66-499	31	59-335
17 to 18	68-765	31 to 32	68-890	17	66-159	32	58-707
18 to 19	68-772	32 to 33	68-901	18	65-798	33	58-061
19 to 20	68-779	33 to 34	68-912	19	65-417	34	57-397
20 to 21	68-787	34 to 35	68-923	20	65-016	35	56-718
21 to 22	68-795	35 to 36	68-934	21	64-596	36	56-017
				22	64-156		

It will not be consistent with the object of the present work to enter into the details on which a map of the world is to be formed, but it will suffice merely to lay down such rules as are absolutely essential for projecting a map of any portion of British India. We cannot, therefore, serve this purpose better than by giving the memorandum of instructions for describing the graticule of maps comprising small portions of the globe, drawn up by the late Col. Blacker, for the use of the Surveyor General's Office, which recommends itself by its remarkable simplicity and accuracy within certain limits. It has long been in use and is very convenient for mapping, as the topographical details within any one section are easily copied and transferred into any other map differing in projection, or in central meridian. The limits to which it is applicable, is confined to about 100 square degrees. The objections to the method are, that it is an empirical process being based upon no *known projection*, and that the protraction it gives rise to, be it performed with as much care and skill as possible, has always a tendency to generate error because it is not laid off from one common origin, on the contrary, the spaces are built one on the other, whereby the error in any

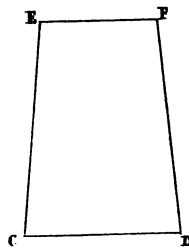
point is carried on through all the succeeding ones. Where great accuracy is sought for and the extent of the map is considerable, it becomes necessary to resort to the principles of conical development, and to protract by means of co-ordinates and a common origin. For this purpose some new Tables have been introduced by the present Surveyor General of India, whereby, by means of rectangular co-ordinates from a common origin, the parallels and meridians may be projected to every degree, and to every 2° according to the scale; but these Tables are too extensive for insertion in this work.

Col. Blacker's memorandum. "The following method of delineating the meridians and parallels of a map, although not solely referrible to any of the demonstrated projections, evidently contains so much truth, as to be well adapted to topographical plans embracing a very small portion of the hemisphere.

"By a mechanical operation, so simple as to require but little explanation, is produced a graticule, whose meridians are all equal, are equidistant at all the corresponding points, are intersected by the parallels at equal angles on the same side; and whose parallels consist of parts proportional to the cosines of their latitude.

"These properties will be rendered more obvious by the detailed account of a construction adapted to an assumed case; such, for example, as the delineation of a graticule comprizing 4 degrees of latitude, between the parallels of 20° and 24° , and as many of longitude, on a scale of 4 miles to an inch.

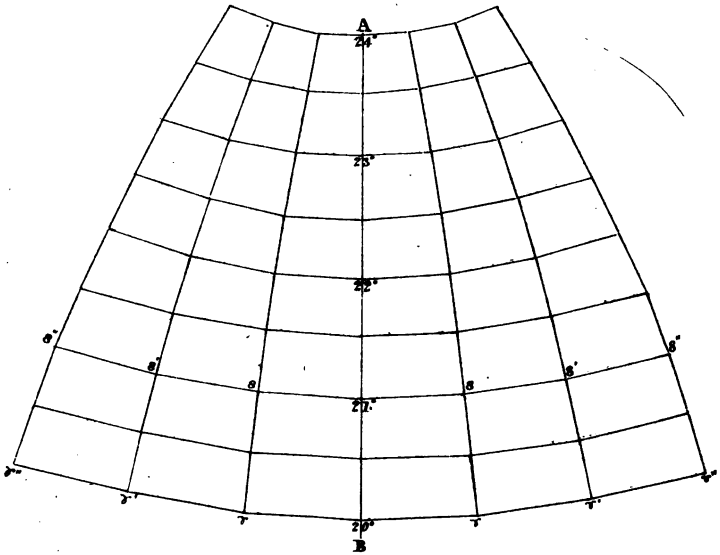
"Let there be imagined a quadrilateral *CEFD*, whose sides shall each be equal to a degree on the meridian, and whose bases shall be equal to half degrees of longitude at the latitudes in which they may be situate; the angles *E* and *F* being equal, as likewise *C* and *D*, it is obvious that the comprized area will



3 Y

represent a portion of the earth's surface, one degree of latitude high and half a degree of longitude broad; and that it may be transferred to any given line, either by determining one angle of the equilateral or its diagonal ED . Let the latter quantity be preferred, since it will be always more correct to lay down a line, than to protract an angle; and suppose the diagonal to have been ascertained.

“Let a straight line AB for the central meridian divide the paper from top to bottom; and at the lower part thereof, lay off the distance $21-20^\circ = CE$. From the point 20° describe on each side of the central meridian, an arc with the radius $CD =$ half a degree of longitude in latitude 20° . Describe similar arcs from the point 21° with the radius $EF =$ half a



degree longitude at latitude 21° . Intersect the two first from 21° with the diagonal distance ED , and the two last from 20° with the same distance. These several intersections $\gamma \delta$, will obviously be points correspondent to D, F , and may be joined accordingly to the other points.

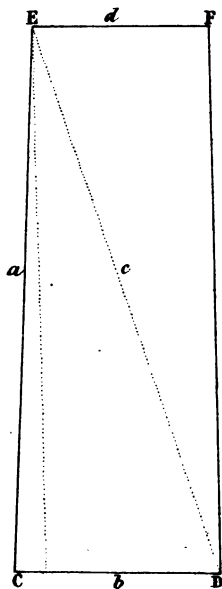
“If a similar construction be repeated by applying the same quadrilateral to the new sides δ , a fresh set of points $\gamma' \delta''$, will be obtained, and will supply the means of continuing the operation still further.

“Two series of points $20^\circ \gamma''$ and $21^\circ \delta, \delta', \delta''$, will be thus generated at the distance of a degree of latitude from each other. They may be connected in the direction $21^\circ \delta$, &c. and $20^\circ \gamma$, &c. by which means will be described two parallel lines of sensible curvature; and again joined in the directions $\gamma\delta, \gamma' \delta', \gamma'' \delta''$, &c. which will form parts of different meridians half a degree asunder. As it is usual on a scale of 4 miles to an inch to draw parallels at every 30 minutes' distance, the last mentioned meridional parts may be bisected, and the points of bisection connected for a new parallel. If similar constructions be extended to the right and left of the intervals $22^\circ-21^\circ, 23^\circ-22, 24^\circ-23$, it is evident, that the graticule will be complete, and have all the properties claimed for this method, as far as is consistent with graphical means.

“The convergency of the meridians will however not be sensible near the central line of the paper; but perhaps there is no other so simple method of delineating them, even as right lines, and at the same time indicating all their intersections with the parallels of latitude.

“It remains now to be seen, how the diagonal ED , which has been assumed as known, shall be obtained; and for this purpose let a line be imagined parallel to FD , from the point E . It will evidently be one side of an isosceles triangle whose base is $= CDEF$, and whose remaining side is $CEFD$.

“Denoting therefore, the side CE by a , CD by b , EF by d , and the diagonal



ED by c , we have in the isocetes triangle, $\text{Cos } C = \frac{b-d}{2a}$,
 and in the obliqueangled-triangle DCE $c^2 = a^2 + b^2 - 2ab \text{Cos } C =$ (by substituting the value of $\text{Cos } C$ already found,) $a^2 + b^2 - 2ab \frac{b-d}{2a} = a^2 + b^2 - b^2 + bd = a^2 - bd = a^2 \left(1 + \frac{bd}{a^2}\right)$, and therefore $C = \sqrt{a^2 \left(1 + \frac{bd}{a^2}\right)}$
 $= a \sqrt{1 + \frac{bd}{a^2}}$

Type of the Calculation.

$a = 60532$ Fathoms, $b = 28604,5$ Fathoms $d = 28419,5$ Fathoms.
 $\log. b = 4,45643$ $\log. a = 4,78198$
 $\log. d = 4,45362$
 $\text{com. log. } a = 5,21802$
 $\text{idem} = 5,21802$

 $\log. \frac{bd}{a^2} = 9,34609$
 $1 + \frac{bd}{a^2} = 1,22187$

 $\log. \text{do.} = 0,08702$ whose square root $= 0,04351$
 $\log. c = 4,82549 = 66910$ Fathoms.

“ In like manner may the diagonals of the remaining quadrilaterals be determined; and when reduced, with the other parts, to the scale of the map, will give at once in inches, the sides a , b , d , and diagonal c for every latitude.

“ In the present supposition, the ratio of the scale is $\frac{1}{253440}$; by which therefore dividing the foregoing quantities we shall have

$a = 17,20$ inches
 $b = 8,18$ „
 $d = 8,07$ „
 $c = 19,01$ „

“ If so far, has been thoroughly understood, there will be no difficulty in using the following Tables, which give the parts

of every quadrilateral of 1 latitudinal degree high, and half a longitudinal degree broad, between the parallels of 8° and 36° .

“ But the scale of 4 miles to 1 inch is not the only ratio which may be required; and therefore other sets of Tables are added for the scale of 8 miles, and of its several multiples by 2, 3, 4 and 6 to one inch.

“ As however the scale decreases, it will be proper that the numbers of degrees contained in the sides and bases of the quadrilateral should increase. The following law will therefore be observed, which is calculated to maintain always a regular curvature, without marking by too sensible an angle, the junction of one quadrilateral with another.

<i>Nos.</i>	<i>Scale of Miles to 1 Inch.</i>	<i>Ratio of Scale.</i>	<i>Degrees in a</i>	<i>Degrees in b and d.</i>	
I	4	$\frac{1}{253440}$	1°	$0^{\circ}, 30'$	} * divide a by 2
II	8	$\frac{1}{506880}$	2°	1,	
III	16	$\frac{1}{1013760}$	3°	1,	} * divide a by 3
IV	24	$\frac{1}{1520640}$	3°	1,	
V	32	$\frac{1}{2027520}$	4°	2,	} * divide a by 2
VI	48	$\frac{1}{3041280}$	4°	2,	

* NOTE.—The divisions here directed, have for object the reduction of the quadrilaterals to the areas proposed to be comprized in the graticule. Thus, in the 1st scale, there will be an intersection at every half degree; in the 2nd, 3rd and 4th, at every degree, and in the 5th and 6th at every second degree.

Table of Quadrilateral parts for a Scale of 4 Miles to 1 Inch.
N. B. $a = 1^\circ$ $b = 0^\circ 30'$ $d = 0^\circ 30'$

Latitude.	<i>a</i> in Ins.	<i>b</i> in Ins.	<i>d</i> in Ins.	<i>c</i> in Ins.	Latitude.	<i>a</i> in Ins.	<i>b</i> in Ins.	<i>d</i> in Ins.	<i>c</i> in Ins.
From 8 to 9	17-18	8-56	8-54	19-19	From 22 to 23	17-20	8-02	7-96	18-97
9 " 10	17-18	8-54	8-51	19-18	23 " 24	17-20	7-96	7-90	18-94
10 " 11	17-18	8-51	8-49	19-17	24 " 25	17-20	7-90	7-84	18-92
11 " 12	17-18	8-49	8-46	19-16	25 " 26	17-21	7-84	7-77	18-90
12 " 13	17-18	8-46	8-42	19-15	26 " 27	17-21	7-77	7-71	18-87
13 " 14	17-19	8-42	8-39	19-13	27 " 28	17-21	7-71	7-64	18-84
14 " 15	17-19	8-39	8-35	19-12	28 " 29	17-21	7-64	7-57	18-81
15 " 16	17-19	8-35	8-31	19-10	29 " 30	17-22	7-57	7-49	18-79
16 " 17	17-19	8-31	8-27	19-08	30 " 31	17-22	7-49	7-42	18-76
17 " 18	17-19	8-27	8-22	19-07	31 " 32	17-22	7-42	7-34	18-74
18 " 19	17-19	8-22	8-18	19-05	32 " 33	17-23	7-34	7-26	18-71
19 " 20	17-20	8-18	8-13	19-03	33 " 34	17-23	7-26	7-17	18-68
20 " 21	17-20	8-13	8-07	19-01	34 " 35	17-23	7-17	7-09	18-65
21 " 22	17-20	8-07	8-02	18-99	35 " 36	17-23	7-09	7-00	18-62

Table of Quadrilateral parts for a Scale of 8 Miles to 1 Inch.—*N. B.* $a = 2^\circ$ $b = 1^\circ$ $d = 1^\circ$.

Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>	Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>
From 8 to 10	17-18	8-56	8-51	19-19	From 22 to 24	17-20	8-02	7-90	18-95
10 " 12	17-18	8-51	8-45	19-16	24 " 26	17-21	7-90	7-77	18-91
12 " 14	17-19	8-45	8-39	19-14	26 " 28	17-21	7-77	7-64	18-89
14 " 16	17-19	8-39	8-31	19-11	28 " 30	17-22	7-64	7-49	18-90
16 " 18	17-19	8-31	8-22	19-08	30 " 32	17-22	7-49	7-34	18-75
18 " 20	17-19	8-22	8-13	19-04	32 " 34	17-23	7-34	7-17	18-69
20 " 22	17-20	8-13	8-02	19-00	34 " 36	17-23	7-17	7-00	18-63

Table of Quadrilateral parts for a Scale of 16 Miles to 1 Inch.—*N. B.* $a = 3^\circ$ $b = 1^\circ$ $d = 1^\circ$.

Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>	Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>
From 8 to 11	12-89	4-28	4-24	13-57	From 23 to 26	12-90	3-98	3-89	13-49
11 " 14	12-89	4-24	4-20	13-56	26 " 29	12-91	3-89	3-78	13-47
14 " 17	12-89	4-20	4-14	13-55	29 " 32	12-92	3-78	3-67	13-44
17 " 20	12-90	4-14	4-06	13-53	32 " 35	12-92	3-67	3-54	13-41
20 " 23	12-90	4-06	3-98	13-51					

Table of Quadrilateral parts for a Scale of 24 Miles to 1 Inch.—*N. B.* $a = 3^\circ$ $b = 1^\circ$ $d = 1^\circ$.

Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>	Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>
From 8 to 11	8-59	2-85	2-83	9-05	From 23 to 26	8-60	2-85	2-89	8-99
11 " 14	8-59	2-83	2-80	9-04	26 " 29	8-61	2-89	2-82	8-98
14 " 17	8-59	2-80	2-76	9-03	29 " 32	8-61	2-82	2-45	8-96
17 " 20	8-60	2-76	2-71	9-02	32 " 35	8-61	2-45	2-36	8-94
20 " 23	8-60	2-71	2-66	9-01					

Table of Quadrilateral parts for a Scale of 32 Miles to 1 Inch.—*N. B.* $a = 4^\circ$ $b = 2^\circ$ $d = 2^\circ$.

Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>	Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>
From 8 to 12	8-59	4-29	4-23	9-59	From 24 to 28	8-60	3-95	3-92	9-44
12 " 16	8-59	4-23	4-16	9-56	28 " 32	8-61	3-92	3-87	9-39
16 " 20	8-60	4-16	4-06	9-53	32 " 36	8-61	3-87	3-60	9-33
20 " 24	8-60	4-06	3-95	9-49					

Table of Quadrilateral parts for a Scale of 48 Miles to 1 Inch.—*N. B.* $a = 4^\circ$ $b = 2^\circ$ $d = 2^\circ$.

Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>	Latitude.	<i>a</i>	<i>b</i>	<i>d</i>	<i>c</i>
From 8 to 12	5-73	2-85	2-82	6-39	From 24 to 28	5-74	2-63	2-55	6-29
12 " 16	5-73	2-82	2-77	6-37	28 " 32	5-74	2-55	2-45	6-26
16 " 20	5-73	2-77	2-71	6-35	32 " 36	5-74	2-45	2-33	6-22
20 " 24	5-73	2-71	2-63	6-32					

Although in the example which has been given a very small area has been employed, this method is nevertheless susceptible of considerable extension. At the same time it has its limits, beyond which the meridians and parallels will lose their proper curvatures. Perhaps 100 superficial degrees will be found to be the utmost extent to which it can be practised, without introducing any sensible distortion; and this area may be indifferently the product of 10 into 10, 11 into 9, 12 into 8, 13 into 7, 14 into 7, &c. whilst it signifies little, which factors express the latitude or longitude.

CHAPTER XXVII.

ON THE CONNECTION BETWEEN THE GREAT TRIGONOMETRICAL AND REVENUE SURVEYS—RATIO OF ERROR—EXTENT OF COUNTRY FOR SURVEY, AND AVERAGE COST PER SQUARE MILE.

No Revenue Survey can be considered complete and satisfactory, unless the errors committed, and the degree of accuracy attained, are distinctly reported on. Without this is scrupulously observed, no confidence can be placed in its results, and as no work whatever, executed by human means, can be free from error, all that is reasonably expected is, that unavoidable errors should not exceed the lowest practicable limits. Every great National survey has a limit of error assigned, and all work exceeding this limit is rejected.

In the large triangulation of the Great
Ratio of Error. Trigonometrical Survey of India, where of course the greatest refinement and most scrupulous care is observed, an error of *one inch* per mile or $\frac{1}{53330}$ in part, amounts to 500 inches or 42 feet, or nearly half a second of latitude in 500 miles, which is the distance between some of the bases. The work is reckoned liable to *half* this error when executed with the great theodolite, and equal to the degree of correctness indicated by an inch per mile, when performed by 18-inch instruments for the subordinate series of triangles; with inferior instruments, or a less careful system, the accumulation of error would be a *foot* per mile, which is equal to a ratio of $\frac{1}{3280}$ in linear dimensions

or $\frac{1}{100}$ in area, or $\frac{1}{10}$ per cent. or 6 seconds in the above distance.

But men trained to this degree of exactness are out of their place in the detail measurements of the Revenue Survey, the valuable qualities of the Trigonometrical Surveyor, which he is obliged to maintain with such care, viz., delicacy of eye and touch, and rigorous modes of thinking, would be injurious in the details, and there would only be a loss of time in changing from one work to the other. They require in fact, people differently trained, with instruments of different calibre, and of different constitutions of mind. The Trigonometrical, from being freed from details, has been able to progress more rapidly, and the great object has been to get the large triangulation out of hand, without it nothing systematic or really trustworthy can be done. Indeed the principal, and the detail work, never could have gone on *pari passu*, and if the latter is based on the triangulation, it cannot be liable to any great accumulation of error, and may be taken up and organized according to the scale required.

The maximum error allowed, in lineal measurement on the Revenue Survey, according to the test it is submitted to by traverse proof, is 10 links in 100 chains equal to 5.28 feet per mile of a mile, but in the actual prosecution of the extensive surveys of the season 1847-48 covering an area of about 16,000 (sixteen thousand) square miles the average ratio of correction employed for the closing of the traverses, is found to be only 2 feet per mile, or rather more than one-third of the allowed correction; $\frac{1}{10}$ per cent. therefore for the pergunnah or main circuit measurement is fully within practicability, $\frac{1}{10}$ per cent. also may be allowed for the area of the district, $\frac{1}{2}$ per cent. for the village survey area, and one per cent. for the interior detail measurement of cultivation and waste.

These are exclusively the errors of measurement. As the computation of the Revenue Survey is based upon the wrong assumption of the earth's surface being a plane, certain dis-

crepancies, no doubt, will arise from this circumstance; but these are invariably very small in comparison with the errors of measurement, as will be evident from the inspection of the following Table, wherein it will be perceived that a Pergunnah, of the average area of 100 square miles, will demand an additive correction of 2,969 *square feet*, on account of the sphericity of the earth, to give the absolute superficial surface or contents of the circuit; the required correction is, however, too small to make its omission of any consequence in a Revenue Survey operation.

Computed plane Area of the Revenue Survey.	Correction for reducing the plane to the spherical Area.	Computed plane Area of the Revenue Survey.	Correction for reducing the plane to the spherical Area.	Computed plane Area of the Revenue Survey.	Correction for reducing the plane to the spherical Area.
Sq. Miles.	Sq. Feet.	Sq. Miles.	Sq. Feet.	Sq. Miles.	Sq. Feet.
1	+	10	+	100	+
2	1	20	119	200	11875
3	3	30	267	300	26719
4	5	40	475	400	47501
5	7	50	742	500	74221
6	11	60	1069	600	106878
7	15	70	1455	700	145472
8	19	80	1900	800	190005
9	24	90	2405	900	240475

But the most severe test to which a Revenue Survey can be subjected, is the comparison of its results with those of a Trigonometrical Survey, and that this comparison may be performed as readily as possible, a due and proper connection between the two surveys is essential, and scrupulously maintained. When this is the case, the principle, agreeably to which the map of the former operation may be corrected by the latter, may be stated as follows :

Suppose A, B and C , to be three points laid down by both these operations, A', B' and C' being the trigonometrical positions, while A'', B'' and C'' are the Revenue Survey sites

thereof. Now take the Revenue Survey map and place A' upon A'' and then if the Trigonometrical line $A'B'$ be laid off agreeably to its azimuth, B' may or may not fall upon B'' , most probably it will not do so. Again, when C' is protracted in the same way as B'' , it will most probably be non-coincident with C'' . Here is therefore a triangular tract of country ABC which is represented by two dissimilar triangles $A'B'C'$ and $A''B''C''$ possessing only a common point A . Assuming the Trigonometrical area $A'B'C'$ as errorless, that furnished by the Revenue Survey, namely, $A''B''C''$ must not only be shifted from its original position, but enlarged or compressed, as the case may be, so as to produce a perfect coincidence with $A'B'C'$. When this operation is gone through, the Revenue Survey points, comprised within the triangle $A''B''C''$, will fall into such positions as would make them correspond with the Trigonometrical sites $A'B'$ and C' .

When the first triangle has been corrected, take the trigonometrical position D' of a fourth point D , and compare it with its Revenue Survey site D'' , it is most likely that D' and D'' will have different positions. Forming as may be convenient ABD or ACD or BCD into a triangle, its Revenue Survey value may, by a process similar to that just described, be made to agree with its trigonometrical value. In like manner the remaining parts of the Revenue Survey map may be altered, so as to make them conform to the correct areas of the Trigonometrical Survey.

When the several parts of a Revenue Survey map are altered in the way abovementioned, the corrections applied are supposed to be small, or if large, they are supposed to be in the same direction and proportional to the areas to be altered. When either of these is the case, a most perfect map will be obtained. But if the corrections are irregular, that is, if they demand unequal enlargement of the different parts of the map, or an unequal compression of them, or if some corrections require enlargement and others compression, the corrected

map, in altering the relative positions of villages, would furnish a distorted representation of the country, which would decidedly be inferior to the original uncorrected map which perhaps did not contain these distortions.

The following comparative Tabular Statement of the numerical values of surveys conducted both in the North-Western Provinces as well as in Bengal, and performed at an interval of 17 years, will best illustrate the preceding remarks.

<i>Revenue Survey of 1832 compared with the Trigonometrical Survey.</i>				
Distances.	From Revenue* Survey.	From Trigonometrical Survey.	Error.	Error upon 1 Mile.
	feet.	feet.	feet.	feet.
Saini to Saroli,	96989	97017	— 28	1·63
Saini to Sirdana,	67571	67639	68	5·16
Saini to Dholri,	107906	108018	112	5·58
Saroli to Dholri,	89681	90249	568	33·50
Saroli to Sirdana,	31170	31194	24	4·07
Godhna to Saini,	214296	214886	590	14·54
Bahin to Chapra,	116637	116046	591	26·66
<i>Revenue Survey of 1849 compared with the Trigonometrical Survey.</i>				
Distances.	From Revenue* Survey.	From Trigonometrical Survey.	Error.	Error upon 1 Mile.
	feet.	feet.	feet.	feet.
Calcutta Base North End to } Barakpur Flag Staff,	19850	19869	— 19	4·89
Ditto North End to Armenian } Church, Chinsura,				
Ditto North End to Fort Wil- } liam Flag Staff,	66636	66721	85	6·72
Samalia to Sarisa,				
Sarisa to Diamond Harbour } Semaphore,	55987	56051	64	6·03
	70196	70326	130	9·77
	22097	22147	50	12·02

* These distances are deduced from the following Tables of the Meridional and Perpendicular Co-ordinates.

From an inspection of these Tables it will be seen that the errors committed on the two Revenue Surveys range from 1.62 to 33.50 per mile on the former and from 4.8 to 12 feet per mile on the latter, and they all lie in the same direc-

<i>Extract from the Delhi and Saharanpur Revenue Survey.</i>		
Stations.	Distances from the Jama Masjid of Delhi.	
	Meridian.	Perpendicular.
Tower at Godhna,.....	N. 5347	E. 3205
Church at Sirdana,.....	" 2733	" 1849
Tower at Saini,.....	" 2142	" 2685
Tower at Saroli near Sirdana,.....	" 2831	" 1387
Tower at Dholri,.....	" 1487	" 1187
Tower at Karol,.....	S. 2641	" 1530
Tower at Bahin,.....	" 3812	" 181
Platform at Chapra,	" 5044	W. 1086

<i>Extract from the 24-Purgunnahs Revenue Survey.</i>		
Stations.	Distances from the North End Calcutta Base.	
	Meridian.	Perpendicular.
Barakpur Flag Staff,.....	N. 283-19	W. 101-30
Armenian Church, Chinsura,	" 1000-31	E. 136-93
Fort William Flag Staff,	S. 823-99	W. 201-59
Samalia Tower,	" 1543-78	" 587-87
Sarisa Tower,	" 2541-88	" 955-26
Diamond Harbour Telegraph,.....	" 2876-66	" 958-71

The distances in these Tables are given in terms of Gunter's chain of 66 feet in length.

Suppose A and B are two points, the distance between which is required to be computed, calling m and p the meridional and perpendicular co-ordinates of the former point, and m' and p' the like co-ordinates of the latter; then the distance of A to B will be equivalent to $\{ (m \oslash m')^2 + (p \oslash p')^2 \}^{\frac{1}{2}}$ That is to say, the required distance is the hypotenuse of a right-angled triangle, whose sides are $m \oslash m'$ and $p \oslash p'$. As for example, the distance from Saini to Saroli = $\{ (2831 - 2142)^2 + (2685 - 1387)^2 \}^{\frac{1}{2}}$
 = 1469.53 chains = 969.89 feet.

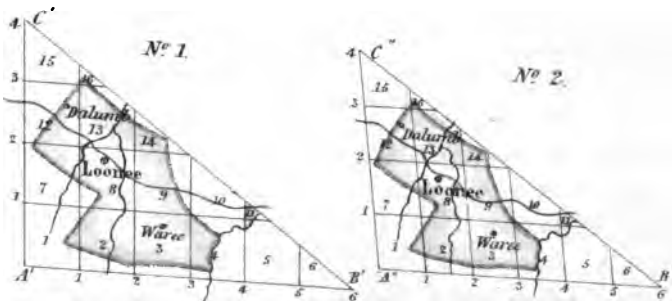
It should be borne in mind, that when either the meridional or perpendicular co-ordinates happen to be of different denominations, the square of the *sum* of the co-ordinates so differing, will require to be taken in lieu of the square of their *difference*. Thus the distance from

$$\begin{aligned} \text{Bahin to Chapra} &= \{ (5044 - 3812)^2 + (181 + 1086)^2 \}^{\frac{1}{2}} \\ &= 1767.23 \text{ chains} = 1166.37 \text{ feet.} \end{aligned}$$

tion, the Revenue measurement being in defect of the Trigonometrical Survey. Taking the smaller of these discrepancies as the error of the Revenue Survey unit, it will be seen that the greatest error actually committed in the more recent operations is only 7 feet per mile.

The azimuth of any side of the large triangles, likewise proves a check on the deduced azimuth of the Revenue Survey as conveyed from one main circuit to another, and this comparison is carefully carried out when opportunity is afforded for so doing.

Having explained in a general way the principle agreeably to which the details of a Revenue Survey may be combined with the results of a trigonometrical operation, we will now proceed to describe the mechanical process whereby that combination may be effected in practice. For this purpose, retaining the characters already used, we will represent by $A'B'C'$ the Trigonometrical and by $A''B''C''$ the corresponding Revenue Survey triangle. Of the three angles of the former triangle, suppose A' to be nearest to a right angle, now take the sides $A'B'$ and $A'C'$ adjacent to this angle and divide the former into m and the latter into n equal parts, m and n being two independent numbers. This done, draw through the dividing points of $A'B'$ parallels to $A'C'$. In like manner through



the dividing points of the latter, draw lines parallel to the former. This will divide the triangle $A'B'C'$ into a certain number of spaces, the greater part of which will be parallelograms, and the remainder, triangles, as shown in diagram No. 1.

After the trigonometrical triangle $A'B'C'$ has been divided in the way above described, the corresponding Revenue Survey triangle $A''B''C''$ may now be subjected to a similar operation by dividing the side $A''B''$ into m and $A''C''$ into n equal parts, and by drawing through the dividing points of either line parallels to the other. This is done in diagram No. 2, and the spaces into which the triangle $A''B''C''$ is divided, are analogous to those contained in the triangle $A'B'C'$, the corresponding spaces in the two figures being marked by the same numerals.

When this preliminary division of the Trigonometrical and Revenue Survey triangles has been made, the details from each of the revenue spaces are *sketched* into the corresponding trigonometrical space. When the sketching of all the spaces is completed, the Revenue Survey details will stand transferred into the Trigonometrical Survey map.

It ought to be observed at this place, that this operation of sketching, which is performed by the hand and the eye, is a guess procedure, and that supposing it to be executed as skilfully as possible, it will always be liable to some error. This error, however, will be reduced to minimum, if the spaces to be sketched are sufficiently diminished in size. For this purpose the most convenient form for a space of this kind is that of a parallelogram, right-angled or as nearly right-angled as possible, with sides varying from one-fourth to one-third of an inch in length. The first of these conditions will be attained by constructing the small parallelograms upon those two sides, which contain either a right angle or an angle, which is more nearly a right angle than either of the remaining angles of the given triangle. As to the second condition, it will always be in the power of a draftsman to fulfil it, by assigning proper values to m and n taking care that these values come under any of the following forms, 2^p , 3^q , $2^p \times 3^q$, the exponents p and q being any integral numbers whatsoever. When the numerical values of m and n are taken equivalent to powers of 2 and 3, or to the

products of those powers, the division of a given line into a required number of equal parts will become as easy as possible, it being carried on by continual bisection or trisection of distances, or by those two operations taken combinedly.

One advantage attending the combination of the Revenue with the Trigonometrical Survey, consists in the cancelment of the errors of measurement which are almost unavoidable in the former operation. The second advantage of such an incorporation, is the elimination of those small discrepancies in computation, proceeding from the wrong assumption made in the Revenue Survey of the earth being a plane. But there is a third, and perhaps the most important advantage, accompanying the union of the two Surveys, which consists in the reference of the Revenue Survey details to proper meridians and parallels. From the manner in which a Revenue Survey is conducted, it may be easily inferred that those lines can never be drawn with any accuracy in the plan of that operation. On the other hand, they can be laid off with the greatest exactness in a trigonometrical map, from the known latitudes and longitudes of the trigonometrical stations contained in it. Suppose the operation of drawing the meridians and parallels is executed in a trigonometrical map, whereto the Revenue Survey details have been transferred, it is evident that that operation will fix the latitudes and longitudes of those details, a determination which will obviously enhance their value as geographical materials, in putting them in an available state for the formation of the general atlas of the country.

It is desirable that the triangulation should always precede the Revenue Survey; it frequently happens, however, that in such a large country as India, the triangulation has not extended over the district marked for the Revenue operations. In this case it becomes necessary to fix very carefully all the conspicuous objects and triple junction Pergunnah Stations from one *permanent point of departure*. From this first station, which

should be a masonry pillar built expressly (if no convenient object presents itself,) all the co-ordinate distances are computed, and are referrible at any subsequent time to the data produced by the Trigonometrical Survey, so that an union with it may afford the means of rectifying the topographical maps. The stations are likewise marked as durably as the means at the disposal of a Revenue Surveyor will permit, and properly connected with every available surrounding object of a permanent character, with a view of easy identification; with the aid of a proper map of the district, and full descriptions of all the stations so fixed, the Trigonometrical Surveyor has no difficulty in taking them all up as secondary points. If the first point of departure is fixed astronomically, it is considered only temporary, being replaced afterwards by values given by the Great Trigonometrical Survey, which are strictly correct as to relative positions, and with which no astronomical measurements executed by a Revenue Surveyor, can pretend to compete.

From the year 1822, when the Revenue Surveys first commenced, up to the year 1830, the rate of progress at which the operations proceeded was extremely limited. Only 3,020 square miles, a little more than half a square degree, had then been performed in seven years, with ten Officers employed in the department, the annual rate of progress of each Surveyor ranging from 50 square miles to 338 as a maximum, and at this rate it was estimated that the area of Bengal and the North-Western Provinces being about 310,000 square miles or 77 square degrees, would require 481 years to accomplish.* The Officers employed in those days, however, had little or no assistance, and the duties performed then by the Revenue Surveyor himself, are now entrusted to competent assistants and sub-assistants with large native establishments under them,

* Account of the present system of Survey, &c. By Captain Herbert, Deputy Surveyor General. Calcutta, 1830.

whilst the Surveyor acts as a Superintendent over the whole as described in a former Chapter, the result of which has been, that during the last 20 years, or since 1830, the whole of the North-Western Province Districts, all Behar and Orissa, and a considerable portion of Bengal Proper, have been completed as detailed below,* no less than 46 districts of unsettled estates amounting to 101,519 square miles, and 13 districts of Bengal and Behar perpetually settled estates, yielding an area of 53,295 square miles have thus been surveyed in detail and mapped, leaving twenty districts of Bengal, comprising 57,990 square miles, to be taken up, five of which are now in hand.

In addition to this, the newly acquired territory of the Punjab and Cis and Trans-Sutledge States have come under the

* UNSETTLED DISTRICTS SURVEYED.

1. Paneeput.	23. Futtehpoore.
2. Hurrianah.	24. Humeerpoore.
3. Delhi.	25. Banda.
4. Rohtuck.	26. Allahabad.
5. Goorgaon.	27. Goruckpoore.
6. Suharanpoore.	28. Azimghur.
7. Mozuffunghur.	29. Jounpoore.
8. Meerut.	30. Mirzapore.
9. Boolundshuhur.	31. Benares.
10. Allyghur.	32. Ghazepoore.
11. Bijnour.	33. Jolun.
12. Moradabad.	34. Dehra Doon.
13. Budaon.	35. Bhuttianah.
14. Bareilly.	36. Sohagpoor.
15. Phillibeet.	37. Ramghur.
16. Shahjehanpoore.	38. Ajmere.
17. Muttra.	39. Mairwharra.
18. Agra.	Total, N. W. P.
19. Furruckabad.	40. Pooree.
20. Mynpooree.	41. Cuttack.
21. Etawah.	42. Balasore.
22. Cawnpore.	43. Cachar.
	44. Jynteah.
	45. Chittagong.
	46. Assam.

SETTLED DISTRICTS SURVEYED.

47. Midnapore.	55. Purneah.
48. Hidgelee.	56. Tirhoot.
49. Hooghly.	57. Maldah.
50. Shahabad.	58. Bhangulpore.
51. Sarun.	59. 24-Pergunnahs.
52. Patna.	—
53. Monghyr.	—
54. Behar.	59. Total Surveyed.

DISTRICTS UNDER SURVEY.

1. Rajshye.	5. Goalparra.
2. Beerbhoom.	—
3. Baraset.	5. Total.
4. Mymensing.	—

DISTRICTS FOR SURVEY.

1. Nuddea.	10. Dacca.
2. Jessore.	11. DaccaJellalpoore.
3. Burdwan.	12. Backergunge.
4. Bancoorah.	13. Sylhet.
5. Dinagepoor.	14. Tipperah.
6. Moorshedabad.	15. Bulloohah.
7. Bogra.	—
8. Rungpoor.	15. Total.
9. Pubna.	—

Revenue operations, and afford a fine field of employment for the department.

The total area of the British possessions in India, including Scinde, Punjaub, Jullundhur Dooab and Tenasserim, has been carefully estimated at 800,758 square miles, and the Native States at 508,442 square miles, making a grand total of 1,309,200 square miles, as the area of British India. This vast superficial extent of territory is confined within a length of 11,260 miles of external boundary. The *inland* frontier from Tenasserim round by the Himalayan range of mountains to Cape Monze in Scinde, is 4,680 miles, whilst the *coast* line from Singapore round the Bay of Bengal, up the Malabar Coast to Kurrachee, is 6,580 miles. Of the Native States, about 200,000 square miles are already surveyed, leaving about 308,442 almost all wild hilly jungle and of little value, to be taken up.* The proper mode of filling up these extensive tracts of country, which are not likely to come under the operations of the *Revenue* Survey, (supposing the latter to be confined to our own, or the Regulation Provinces) will be by minor Triangulation and the Plane Table. The $\frac{1}{2}$ inch or 2 miles = 1 inch scale, will perhaps be the most suitable for

* Of the Native States some of the following are the most conspicuous.

<i>Estimated Area.</i>	<i>Sq. Miles.</i>	<i>Estimated Area.</i>	<i>Sq. Miles.</i>
Oude, (Lucknow,)	23,738	Bhopal,	6,764
Mysore,	30,886	Rewah,	9,827
Hydrabad, (Nizam's,)	95,337	Protected Seikh and } Hill-States,	15,188
Jodhpoor,	35,672	Oudeypore,	11,614
Gwalior,	33,119	Sattara,	9,061
Bhawulpoor,	20,003	Kolapore,	3,445
Golab Singh,	25,123	Cutch,	6,764
Berar, (Nagpore,)	76,432	Kotah,	4,339
Jeypore, &c.	15,251	Indore,	4,467
Bickaneer,	17,676	Travancore,	4,722
Jeysulmeer,	12,252	Ulwur,	3,578
Baroda and Kattyawar,	24,249	Bhurtpore,	1,978
Jhansee,	15,570		

the nature of most of these countries, of which on account of their connection with us, the liability to lapse to the Paramount Power, and likelihood of becoming the scenes of Military movements, we require to have a good general survey. For topographical work, in filling in triangulation with the Plane Table, one man ought to be able to survey 16 square miles per diem, viz., 4 miles by 4 miles—on the $\frac{1}{4}$ inch or 4 miles to 1 inch-scale, or per season of 6 months' duration about 2,500 square miles. For the $\frac{1}{2}$ inch or 2 miles = 1 inch scale, only 4 square miles per diem can be executed, or about 600 square miles per season, and so on inversely as the squares of the scales.

Of the area abovementioned, the countries lately lapsed to the British, and which may now be seen within the red color on the published maps, have been included. The Jullundhur Doob with the Kohistan, is about 16,400 square miles, and the Protected Seikh and Hill States 15,187 square miles, the Punjab proper may be said to be 78,000 square miles more, and these provinces are now gradually coming under the *Revenue* operations. Indeed 20,000 square miles of the Cis and Trans-Sutledge States have actually been completed. The province of the king of Oude may likewise lapse some of these days—its area is 23,738 square miles. The Gwalior territory comprises 33,119 square miles, and the Saugor and Nerbudda 33,775 square miles.

As a sample of the progress now made by the combined efforts of the Officers employed on this side of India, and the cost at which the work is performed, the following analysis of the general average rates per square mile, with the total area completed, is given for the North-Western Provinces from the year 1833, and for Bengal from the year 1838, the first commencement of operations down to the present time. The average for the North-Western Provinces in the 12 seasons' work, amounts to Rs. 16-8-8 per square mile, and for Bengal it is in a similar

Average Cost.

period Rs. 20-14-10 per square mile, whilst the general average on the whole area executed, is only Rs. 18-6-8 per square mile. In the two seasons of 1847-48 and 1848-49, upwards of 16,000 square miles of country appear to have been surveyed by the united exertions of eight different parties in the two provinces.

North-Western Provinces.					Bengal Provinces.				
Season of Survey.	Area Completed.	General Average Rate per Square Mile.			Season of Survey.	Area Completed.	General Average Rate per Square Mile.		
	Sq. Miles.	Rs.	As.	Pie.		Sq. Miles.	Rs.	As.	Pie.
1833-34	3747	29	4	1	1838-39	1901	60	0	1
34-35	5282	24	7	5	39-40	2450	40	9	4
35-36	5391	27	5	11	40-41	5145	23	3	4
36-37	7455	23	15	0	41-42	9132	22	5	7
37-38	12400	13	7	0	42-43	6085	20	13	0
38-39	10974	13	15	8	43-44	7079	18	4	4
39-40	12898	11	12	5	44-45	7043	16	10	2
40-41	12898	11	12	5	45-46	8967	12	10	8
46-47	9583	20	1	7	46-47	7429	14	9	5
47-48	8967	14	4	5	47-48	7097	18	2	5
48-49	9858	12	5	0	48-49	6243	21	0	4
49-50	5552	22	12	0	49-50	5162	24	14	10
Total, 12	96636	16	8	8	Total, 12	73684	20	14	10

	Area in Sq. Miles.	Cost in Rs.	Rate E. A. P.
Total of the two Provinces,	172,321	31,74,101	18 6 8

It appears, that as the surveys advance, it tends to diminish the cost per mile in each succeeding year, caused by the facility acquired by the well trained establishments, and the very efficient mode of working them exercised by the Superintending Officers. The expense of a Revenue Survey, however, is much influenced by local peculiarities, and even allowing for the difference amongst Surveyors, some being more skilful, active, and capable than others under precisely the same circumstances of doing more work, it often happens that the utmost endeavours of the most energetic Officers will not produce so low a mileage cost, as others who have more favored ground to go over. In the circuit system work of the Revenue Surveys, *the size of the villages* is the grand secret, if

the average size is large, above a square mile, as in the North-Western Provinces, a good outturn may be expected, and consequently a reduced cost, but in Bengal where the villages do not average above *half* a square mile, it is impossible to compete with the extraordinary cheapness, which some of the old Surveyors attained, neither indeed is such a thing desirable with reference to the accuracy demanded in the present day. If 3,000 square miles and upwards is given in by a single Surveyor, the results must partake of that haste with which the country is got over and eventually prove of an inferior order.

A survey establishment is always proportionally more expensive, the less complete it is; the chief expense being the salary of the Surveyor and the European Assistants. It should therefore be kept up in as effective a state as possible with a view of turning it to the best account, and by a proper division of labor, as economical a survey may be obtained as local circumstances will permit. At the average rate of progress already made in the Bengal Provinces, it may fairly be anticipated, that what remains to be done will not occupy a longer period than ten years more, when in addition to a good Topographical Survey we shall have a complete and detail record of every estate paying revenue to Government, and at the present average rates the cost may be calculated at about $11\frac{1}{2}$ lacs of Rupees, which added to $15\frac{1}{2}$ lacs already expended, will make 27 lacs as the entire expense for Bengal, Behar, and Orissa.

Part IV.

ON THE KHUSRAH,

OR NATIVE FIELD MEASUREMENT.

CHAPTER I.

THE chief object of the Revenue Survey in India, is either the formation of a new settlement with the Zemindars and other petty landowners and tenants, or, where the provinces are perpetually settled under Lord Cornwallis' Act of 1790 as in Bengal and Behar, the definition of every estate on the Collector's Rent Roll, and to determine the relation of land to jumma, by the ascertainment of the areas and boundaries of estates and mehals.

Preliminary
Remarks.

In very many instances, these estates are so small or so scattered and intermixed, that the Professional or Scientific Survey is unable, on account of the enormous expenditure it would involve, to define such minute parcels of land. For the general purposes also of the current revenue business of the district, a record in the vernacular language is essential, and without which the people would be kept in ignorance of the result of the investigations pursued.

For this purpose, therefore, it is necessary for the Surveyor, in addition to his own scientific operations, to carry on a *Khusrah* or *statement of measurement of land*, according to the native system, known and appreciated by the inhabitants of the district, and performed by natives, who are well acquainted with the nature of the tenures, the general capabilities of the soil, and the current dialect language.

Such a measurement of the North-Western Provinces has been entirely completed, and a settlement of the land tax concluded, but in the Lower Provinces, the records in the Revenue Collectors' Offices, and upon which the whole fiscal and judicial business is conducted, actually shew nothing more than the mere name of the estate and the amount of land-tax (jumma) paid by the proprietor, and even this is frequently obscure and undefined, whilst the villages and portions of villages of which it consists, scattered perhaps in different parts of a Pergunnah are known only to the proprietor, or his agent. The chances, therefore, of an auction purchaser obtaining uncontested possession of an estate are very remote, and in many cases where Government have become purchasers, the authorities have been unable to trace the lands composing the estate; or else, what they have been successful in finding, has been insufficient to meet the jumma assessed. The absence of all authentic data regarding their districts, having long been severely felt by the local civil authorities, the Revenue Survey has been ordered to extend its operations over the whole of the Regulation Districts of Bengal, and we propose to treat of the method of conducting an efficient Khusrah measurement and to explain the difference necessary to be observed in *Unsettled* Districts where the assessment follows in the train of the survey, and in the perpetually *Settled* Provinces, where no settlement is intended, but for which a faithful record of estates paying revenue to Government is so much needed.

It must first be understood that the "Khusrah" is a distinct operation altogether from the Professional Survey; the latter is performed on scientific principles, with first-rate instruments and by experienced Europeans and East Indians, aided also by natives trained and educated for the purpose; the former, on the contrary, appears to be conducted by the rudest methods, and by an inferior, though intelligent class of natives, the only instrument used being a rope, rod or chain according to

the primeval custom of the district. With no compass, or any thing, but his rope to guide him, the native Ameen is expected to measure a village, the total area of which must agree with the area defined by the Professional Survey within a certain percentage, and to deduce the intermediate detail areas of every species of "land under cultivation," "thrown out of cultivation," that which is "fit for cultivation," "waste or jungle," "sites of villages and gardens," "topes of trees," &c., the separate contents of which shall, in the aggregate, make up the correct total area of the village, to form the basis of the Revenue Assessment of the *Mouza* or village.

As a general rule the term "*Measurement*" is always applied to the *Khusrah* proceedings, while that of "*Survey*" more properly belongs to the scientific portion of the operations.

As a preliminary and most important part of Survey Operations, the accurate demarcation of boundaries, and settlement of disputes, is carried on by a distinct establishment specially appointed

Demarcation
of Boundaries.

for the purpose, and although this duty is not actually in the province of the Surveyor, forming as it does a judicial proceeding, still the working of the system and its connection with the survey, should be fully understood, its notice here therefore will not be out of place. A Covenanted Civil Officer vested with the powers of a full Collector, having a very efficient establishment under him, consisting of Uncovenanted Deputy Collectors, Peshkars, and Ameens, of the strength noted in the

FOR 12 MONTHS.		
2 Uncovenanted Deputy Collectors, at 400, ... }	Rs.	9,600
4 Peshkars, at 40, "		1,920
12 Peadahs, at 3, "		432
FOR 6 MONTHS.		
40 Ameens, at 17 Rs. }	"	4,080
each, }		
12 Peadahs, at 3, "		216
Per Annum,	Rs.	16,248

margin, precedes the survey, in such a way, that the Surveyor may always find *adjusted* boundaries, and plenty of them, to keep his parties in full work. The chief object of this Officer is to keep so well in advance, that no hindrance whatever

may occur to the Surveyor, he has to furnish a sketch map of the boundary of every village demarcated, exhibiting the points at which mud pillars (or *Tháks*) or other marks have been erected at certain measured distances, generally about 200 to 300 feet apart, together with a file or *misl*, explaining the position of these marks and the names of adjoining villages. At every principal angle or bend of the boundary a mud pillar (or *Dhue*) such as is seen in Plate No. V., is erected, and at all triplejunction points these distinguishing marks are found, about 5 feet high, and at the intervening distances smaller marks, bamboos, sticks, or smaller mud pillars suffice.

An acknowledgment (*suppoordnameh*) from the several parties concerned as to the accuracy of the boundary laid down, and for the preservation of the marks pending the survey—and a *roodad* explaining any peculiarities in the village—the nature and names of the included mehals or estates, and whether there are any other lands belonging to the village, detached in other parts of the pergunnah; or if it contains interlaced lands belonging to other villages—together with remarks as to the prospering condition of the village, or otherwise, the estimated proportion of cultivation to waste, and so on—are included in the file.

As soon as the Pergunnah is completed a correct list of villages is made out, together with a general rough sketch or *moojmillee* map, exhibiting every village circuit in its proper relative position. These documents are forwarded for the use and guidance of the Surveyor, and without which it would be difficult for him to proceed. So much importance is placed on the due performance of this duty, that Surveyors are positively interdicted from surveying any boundary, unless they are in actual possession of the demarcation papers.

They are thus entirely dependant on the proceedings of the Settlement Officer for a fair field to labor in. When the marks are erected in the field they are frequently destroyed, both by the elements and by the village people, without therefore

the sketch map to guide him, the assistant employed on the boundary survey is liable to take up a wrong boundary. In some instances, great confusion has arisen and revision become necessary, from the absence or inaccuracy of these documents, the village *Thakbust* map therefore is required for constant reference and is placed in the hands of the European Assistant, who undertakes the Professional Survey. A specimen of this map is given in Plate XIII., and it may be observed that the outline boundary should be sufficiently approximate to the map by actual survey, as to admit of easy comparison, and the professional map of every village must actually assimilate with this *Thakbust* before it can be passed, a statement to this effect being appended to every map by the Surveyor. In some districts, however, the maps are not so good, the bends and turns in the boundary being sketched in, without reference to their actual length by measurement, and which frequently distorts the shape of the circuit very considerably, rendering a comparison with the true surveyed boundary impracticable. To obviate this, a scale has been introduced, and even a compass put into the *Thakbust Ameen's* hands, with which he goes round the circuit, taking a bearing for every bend, and laying the same down on his map by the aid of a paper protractor. This system is now generally introduced in Lower Bengal where the intricacies of the boundaries, and the insubordinate conduct of both landowners and *ameens* rendered it more than advisable to adopt some further check on the demarcation operations, to prevent if possible the system of guess work, so frequently resorted to by the latter class of persons.

The nature of the village boundaries in Bengal is such, that it is feared even the present complete and expensive operations are insufficient to enable entire confidence to be placed in the maps; without any *natural* boundaries or permanent landmarks, there is no method by which the lines and bends represented on the maps and called

boundaries, can be proved mathematically, and until a more stringent law is enacted, to make the investigations now carried on, permanent and unalterable, even in the Civil Courts, the zemindars will oppose and obstruct, and be perfectly indifferent to the recorded boundary of their villages, knowing that the question of their *rights* of property, is not effected by the investigations under Regulation VII. of 1822, by Uncovenanted Deputy Collectors, or even by the Settlement Officer who exercises the powers of a Collector.

It is very evident that with such precautions, and with such labor and expense, if village boundaries, obtained by three distinct investigations, compared and found critically to coincide one with the other, and all disputes carefully settled and decided as well as attested by surrounding zemindars, are afterwards to be impugned, and on subsequent complaint in the Civil Courts are found to be at variance with the absolute limits of the estate as then pointed out, then no blame can be attached to any one, but the zemindars themselves, combining together fraudulently to mislead, or else, carelessly indifferent or ignorant of that which the Government takes such pains to ascertain. By making the proprietors of the soil fully alive to the final importance of the survey operations as regards their *rights*, this evil can alone be remedied. The result of the survey in Bengal may then prove of equal value to the Government as it now does in the North-Western Provinces. In every local Court, the survey records are there appealed and referred to, with confidence, to the unbounded advantage of every department of public business, and the ease and relief of every official.

The present extent of survey establishments, and the rapid and efficient manner in which they have been brought to carry on their operations, renders it imperative on the Revenue Officer to be at least one season in advance with

the demarcations. Without this, the Surveyor could not take the field in December with any chance of finding uninterrupted work, and unless the demarcations are well *in advance*, the operations become a mere clog on the Surveyor, adding greatly to the expense of the survey, and rendering nugatory also the heavy expense of the revenue investigations. It will also be apparent that the utmost necessity exists for all the *disputed cases* to be properly adjusted and settled *prior to survey*, without this *sine quâ non*, double measurements must be resorted to, and the records of the survey not only delayed but thrown into confusion.

The Pergunnahs demarcated one season, may occasionally require to have their *Thâks* or marks, which have been washed or blown away during the intervening rainy season, re-erected: for this purpose, merely a few Ameens sent round again early in October or November, are sufficient to induce the village authorities to replace the marks according to the investigations previously conducted, and thus Surveyors are amply provided for starting their work at the commencement of each Field season.

The "Khusrah" as well as the Professional Survey is done *mouzawar*, or village by village. In *Unsettled* districts it is necessary to measure by Khusrah every village and carefully to investigate into all the details of the qualities of the soil, nature of the crops and every other description of information tending to facilitate the assessment with every individual proprietor, and at the same time to preserve the rights of their subordinate *ryuts* or cultivators of the soil, by recording their separate fields, and the terms on which they hold them from the zemindar, and to render the duties of the Collector of Revenue, as plain and distinct as possible.

In *Settled* districts, the areas and boundaries of mehals being all that is required, the Professional Survey is able of itself to ascertain this, when an estate consists of one or more integral

Difference between Settled and Unsettled Provinces.

and compact villages—and no *Khusrah* is therefore necessary. But where the villages contain such an intermixture of property that the Professional Survey is unable to define it, then the native field measurement or *Khusrah* is essential to supply the deficiency. By these means the scattered lands of every mehal or village, however intricate, are brought together, and the aggregate areas thus obtained, are recorded on the plans of the Professional Survey. The *Khusrah* measurement therefore is only resorted to, when the division and intermixture of property is so minute and intricate, that the details cannot be professionally surveyed, except at a most disproportionate and unwarrantable expense. Where there may be only one or two parcels of intermixed lands in a village, of course the whole village should not be measured by *Khusrah* on that account, these parcels may easily be shewn by the Professional Survey, but where estates are held *ijmallee*, or in shares, and the lands are divided field by field, *Khet-but* (in Behar phraseology,) or *Petulgolah* (as it is termed in Bengal) the *Khusrah*, properly attested by the parties, is the only satisfactory, if not the only attainable, record of the state of the property. In *Settled* provinces therefore only a small moiety of the villages come under the *Khusrah* operations, generally not more than about 15 per cent. on the entire area, and as the nature of the soil and crops is a point of secondary importance, the labors and anxieties of the Surveyor are greatly diminished and a vast saving of expense also effected.

CHAPTER II.

ON THE MODE OF PROSECUTING THE KHUSRAH.

THE number of villages requiring this process being ascertained from the lists furnished by the Demarcation Officers, the Surveyor at the commencement of the season appoints as many Ameens as he calculates will be able to keep pace with the professional work, (a very important point) and in most of the surveys of late years from 100 to 200 qualified men have been employed annually. The correct boundary of the village having been demarcated as before explained, the Ameen is deputed with suitable Perwannahs, (written orders or summonses) and copies of the Thakbust papers for his guidance; he proceeds at once to acquaint himself with the names of the chief Proprietors, Farmers and Gomastas, (or agents) and speedily enters into arrangements with them, for commencing the measurement of their fields, and demands the records of any former measurement which may be in existence, to assist him in his investigations, and to enable him to have some clue as to the rights of property in the village. All preliminaries being settled, which takes a considerable time to effect with recusant and unwilling landowners on the one side, and exacting Ameens on the other, the Ameen commences to measure each field or plot of ground with

the linear measure in general use in the Pergunnah or District, most commonly a rope of raw hemp, or a short

FORM OF THE KHUSRAH OR CHITTAH.

Mouza Ramchunderpore: Pergunnah Meyyansull: District 24-Pergunnahs.

This village is measured with a chain of 80 haths long, by Madhub Chunder Ghose, Ameen, in the Year 1848.

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
Number of Dagh or Field.	Number on Towlee or Collector's Rent Roll.	Name of Mehal.	Name of Malikhana or Proprietor.	Name of Jotedar and relative position of Fields with preceding one.	Length in Russees.	Breadth in Russees.	Area in Beegahs.	Description of Soil.	Crops.	Remarks.
1	255	{ Khoord } { Rajpore, }	{ Horololl } { Mittree, .. }	Horee Patales commenced on Southern Boudary of Gopalpore, on waste land of Kundan-ge,	2 16½	0 10½	B. C. C. 1 14 10	Salee Putteet,	.....	Government holds a 4 ans., 12 grundahs share in this village. The beegah is one russee of 80 puckha haths long, by the same breadth.
2	260	Ditto,	{ Soond-ree Das-see,	On South of above waste land, Jotedar Kistoroy Takoor,	1 7	0 17½	1 3 10	Ayrum or let } Quality, } &c.	Garden,	

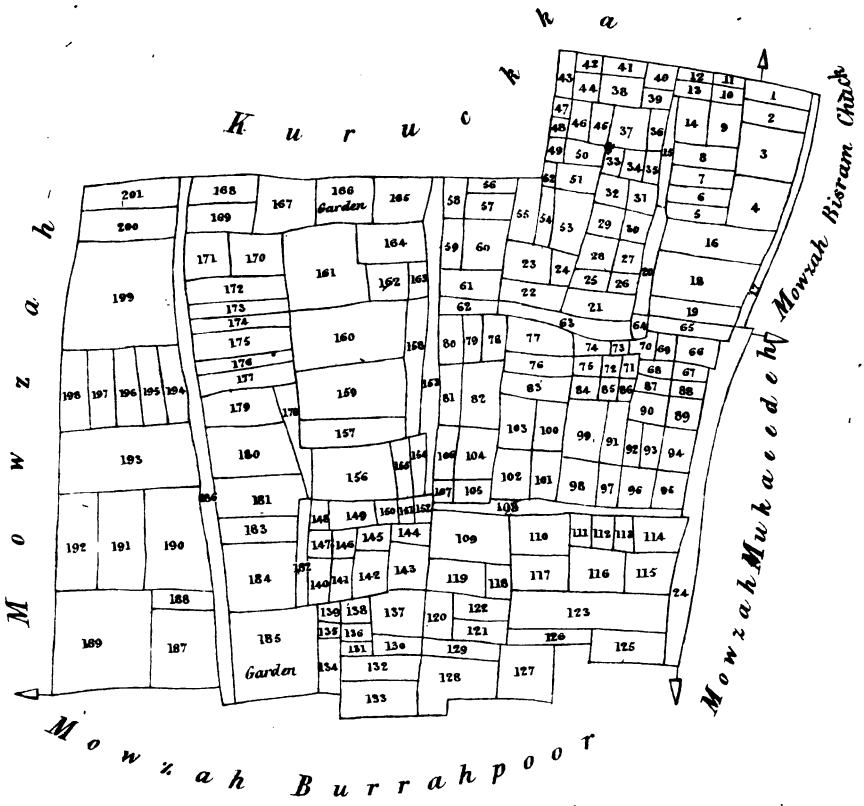
bamboo held in the centre, and thrown down touching the ground at either end. Every field is thus measured in the form of a parallelogram by simply taking the length and breadth, (or the mean of several measurements where the sides are unequal,) the position with reference to the adjoining fields being also carefully recorded. The measurements, whatever they may be, are called out loudly, for the information of attending witnesses, and of the *rojo-nuvees*, or village writer, who follows the Ameen, and takes a verbatim copy, for the satisfaction of the proprietors, and as a check against the Government functionary.

The field measurements are entered in a Tabular form of the description shewn in the preceding page, every holding and parcel of land differing in quality, or coming under the various denominations of settlements, whether lakheraj, (rent-free,) &c., are recorded separately, each field being distinctly noted as lying to the North, East, South, or West of the preceding one, and distinguished by the name of the jotedar (or cultivator) as well as proprietor, together with such other natural landmarks as may exist.

At the same time with the entry of these particulars, the measuring Ameen constructs a *rough eye-sketch* (or *shujreh*) of the relative positions of all the fields, numbered to correspond with the Register or Field-book—and which therefore forms a complete index to this document. This map is merely traced by the hand, without scale, rule or compass—but by constant practice and a naturally quick eye, the Ameen is able to put each day's work together, so that when the whole village is completed, the exterior outline or contour of the boundary, bears a sufficient resemblance to the professional map, as to admit of easy comparison, and considering the means employed, and the large number of fields so put together, averaging from 1,000 to 1,500—it is only to be wondered at, that such accurate and useful results are arrived at. Plate XIV. is a

The Khusrāh
Field-book.

Specimen of Khusrah Field Map,
or Shujreh
Mowzah Moschreemookhrah
Purg^h Manjhee Zillah Sarun.



Shaghumlall Aunon

(S^d) W^m Maxwell Lieut
Digitized by Google
Revenue Surveyor

specimen of an actual measurement prepared in the way described in the Sarun District. This map and register affords information to the most minute details, as to the position, size, and condition of fields, the roads, watercourses, nullahs, &c., within the limits of the village, forming a complete foundation for the abstract of estates (or *khatteeawonee*) required for the purposes of assessment, or the Mehalwar Register, where no fresh settlement is needed. It must here be remarked that the *fields* recognised and adopted on this side of India, are not arbitrary squares and parallelograms formed and moulded at the time of measurement, for the express convenience of the Surveyors or revenue operations, but *bonâ fide* the small and intricate plots of land pointed out by the people of the soil according to their own divisions and subdivisions, and consistent with immemorial right and usage. They manage these things differently at Bombay as will be seen from a pamphlet lately published quoted below.* Although there are some points connected with their mode of conducting the Khusrah, especially as regards the permanent fixture of the boundaries, and the completeness and sufficiency of their law and consequent understanding with the people, which might be followed with advantage, we extract three rules which would appear somewhat at variance with the preconceived notions on this side of India.†

* *Vide* Official Correspondence on the System of Revenue Survey and Assessment in the *Bombay* Presidency. Printed by order of the Government of Bombay, 1850.

† Rule 1, Page 4. "The number of acres for each description of soil and culture capable of cultivation by a single pair of bullocks having been determined, the size of the fields should be so regulated as to contain from this to *double this number* of acres."

Rule 7, Page 21. "When two ryots hold a field and one of them relinquishes his share, or dies without heirs, the share thus lapsing is to be offered in the first instance to the other sharer before it is offered to any other party, and in event of the said sharer declining it, and, no other party applying to take it up, *the former must relinquish his share too*, and allow the whole field to become waste!"

The system of the Revenue Survey at Bombay appears very different to what we have endeavoured to describe in these pages, and it is not combined with a Professional Survey for the purposes of check or the attainment of geographical information. Our space will not permit of entering further into a comparison of the mode of procedure between the two Presidencies, and we must refer the reader to the work itself for further information on the subject, as well as to the "Directions for Settlement Officers in the North-Western Provinces, published in September 1844," in which very full and valuable details are given as to the whole process of both Khusrah and Thakbust.*

In the definement of so many fields within a small area of perhaps 400 to 500 acres with a common rope, considerable error must be caused; in Khusrah measurements, however, it is not the mere error of bad tools and bad workmanship that is to be guarded against, but the most venal and nefarious practices, for which Ameens are notorious in all parts of India; the frauds and peculations they enter into with the Zemindars require the utmost energy, activity, and watchfulness of Superintending Officers to keep in check. The profession of a Surveyor is always onerous, but when he is invested with the charge of the Khusrah, in addition to his scientific operations, his duties become very arduous and full of anxiety, for without the most incessant check and control

Rule 8, Page 21. "When there are more sharers than two in a field, and any of them relinquishes a share, or dies without heirs, it should be offered as above to the sharers in the first instance, beginning, in event of their failing to settle the matter amongst themselves, with the largest sharer, and so on to the least. If none of these nor any other party be found to take up the relinquished share, *the whole field must be thrown up!*"

* See also "Translation of a proceeding, (or complete Misl) regarding the settlement of a village according to the system pursued in the North-Western Provinces. Published under the authority of the Lieutenant Governor in 1847."

over his Ameen, scattered through perhaps 150 villages and a superficial area of one hundred square miles, he never can expect the measurement to proceed systematically, and satisfactory for the purposes of the civil authorities, or free from complaints on the part of the Zemindars.

The check on the total area of the village, as soon as all the fields are put together, and the totals in the Khusrah, or Field-books added up, is easily made by a comparison with the professional area. The two operations are expected to coincide with each other within 5 per cent., though a much nearer approximation is most commonly made; and when we consider the means at the disposal of a Native Ameen, it is a matter of astonishment how such a result is produced. Such is the nicety with which experienced men can bring these measurements, when rigorously watched and superintended, but only when kept in check by the simultaneous procedure of the professional survey, that thousands of villages are annually completed, differing from the true areas much less than the maximum allowance, the average difference frequently being reduced to *one* per cent. on the total area. But besides this primary test, it is essential to examine or *Purtall* a certain per centage of the fields to ascertain if *A* has received more than his proper share, or *B* less, and also to verify the crops or quality of the soil, in which lies the greater chance of the Ameen defrauding Government by describing land as second or third quality, and yielding but one crop, when it is in reality first-rate, and producing two crops annually, and on this essential investigation, depends the amount of sudder jumma (revenue) likely to be collected where an assessment is to follow.

For the detection of such imposture then, *Purtall* Ameen, on suitable salaries of 15 to 20 rupees per mensem, are appointed to go to the village after the Ameen has concluded his task, and re-measure a certain number of fields at

random, and describing the true produce and capabilities of the soil. It is sometimes the practice to measure a line right across the village and to note the several distinct properties as they fall under, or intersect this line of measurement, and by this method a larger number of fields are checked than could otherwise be done. The Khusrah is likewise subjected to the personal supervision in the field of the Surveyor and his European Assistants, and to examination and check as to the accuracy of the figures in the offices. The establishment generally sanctioned for this purpose is as follows :

For 12 Months.	{	1 Head Moonshee at 20 to 30 rupees.
		1 Naib ditto at 15.
		1 Mohurrer at 10.
For 6 Months.	{	4 Purtall Ameens at 15 to 20 rupees,
		8 Peadahs or Measurers at 3,

or one Purtall Ameen to 25 Measuring Ameens, and with such assistance the Khusrah operations ought to proceed systematically and well. Each European Assistant and Sub-Assistant Surveyor performs this field *Imtehan*, or supervision of a certain per centage of the villages within his division, rendering a report of the results, to the Revenue Surveyor after the following form, and this Purtall is filed with the misl.

If, on a comparison of the Ameen's measurement with the professional area, or the Purtall, discrepancies are detected, the offender may be summarily punished by fine, or *in a case of fraud* against Government the case if made over to the Zillah Criminal Court, is punishable by fine to the extent of 200 rupees, or in default of payment to imprisonment for a period not exceeding six months. The difficulty of keeping a large body of Ameens in order, must be obvious, stringent discipline is therefore absolutely necessary, and a single case made over to the Magistrate, invariably instils a most wholesome awe in the rest of the establishment, and the effect produced is most advantageous.

Statement shewing number of Villages (measured by the Khusrah.) Tested by A. B. Sub-Assistant.

Date of Examination.	Name of Purgunnah.	Name of Village examined.	Name of Ameen.	Khusrah Misl.		Khusrah Map.		General Remarks.
				Remarks.	Remarks.	Remarks.	Remarks.	
1847 Dec. 1st.	{ Sukeet, }	{ Sudder- poor, }	{ Seyr Mull, }	{ Size of Fields, accurate pro- gress fair, .. }	{ Intelligible, the Fields easily iden- tified on the ground. }	This village was carefully inspected by me, and the following fields were minutely tested Nos. 99, 98, 219, 245, 234, 244, 275, 287, 288, 292, and 291. I, however, discovered the following incidents, namely, Nos. 291 and 292, amounting to 1 beegah and 4 biswas, were inserted in the Khusrah as ratal or sandy and khakee, and the field No. 288, amounting to 18 biswas, was placed as Khakee and sandy, whereas the two former fields should have been noted as chiknoot abbee, and the last named field as chiknoot chabee, the necessary corrections were made on the spot, and the Mootsudee has been admonished by me against any such errors hereafter. No complaints by Zemindars—measurements completed as far as Field No. 742.		

On the completion of the measurement of a village the Khusrah *misl*, or *chitta*, or Field-book as before described, is copied out fair, and the total area and abstract of details duly recorded on the fly-leaf. This document, together with the field map, is signed by the several proprietors concerned, any

Records how prepared and disposed of.

objections being fully enquired into, on representation to the Superintending Officer. After passing the test of the Purtall, and the total area of the village coinciding within the allowed limits with that of the Professional Survey, the field map is compared with the Thakbust as well as the professional map, and the whole file then made over to the Settlement Officer, duly signed and attested on every leaf, all erasures being specially accounted for. If a settlement follows, a further enquiry is instituted by the revenue authorities as to the description and quality of the soil and crops. The *khatteeawoonee*, or abstract of the number of fields appertaining to each estate, is then made out, and this forms the basis on which the assessment is levied or the Mehalwar Register is constructed in English. On the latter record being formed, with all the statistical information available from the village maps, a volume for each pergunnah is finally deposited in the Collector's office for the benefit of the public service. The vernacular files and Khusrah maps are deposited in a similar manner, and as the attainment and preparation of these documents has been laborious and expensive, so should their preservation and safe custody be equally cared for.

Whatever may be the nature of the Measuring Ameen's record of the soil, or produce, Zemindars have always various objections to offer at the time of signing their agreements, and invariably press for a reduction of the estimate and a further investigation on the part of the Assessing Officer. The point is an important one, and however well a Surveyor may watch over his Ameens, it is almost an impossibility to protect effectually the Government interests in this respect. In anticipation of a new assessment, the people have recourse to all sorts of stratagems, lands are thrown out of cultivation and allowed to run to waste, and vegetation being so rapid in India, a single season is sufficient to prevent a fair identification of the soil. Ameens likewise are notoriously venal,

Objections to
Ameen's pro-
ceedings.

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and an understanding is soon made with the village authorities, who are in the habit of paying a certain black mail, for every beegah, the quality of which is underrated. As detection, however, is more than probable the promises made at the time of measurement are not always carried into effect by the Ameen, when he lodges his Khusrah, and the deception is not discovered by the Zemindar until the time of settlement arrives, and then he enters general complaints against the measurement.

The duties of Ameens are extremely irksome and laborious; perfectly dependant on the will and pleasure of Zemindars and other lazy village authorities, for the prosecution of their daily work, and for which they are paid very insufficiently by Government, it is not surprising that they must live by other means, the remuneration therefore comes from the people of the soil. Where payment is made by contract, the Ameen must be compensated for the delay which the Zemindar deems it actually necessary to his dignity to observe, and until several petitions have been made against him, he does not dream of making a move to co-operate with, or assist the Ameen. Such a system is much to be regretted, but no endeavours, on the part of a Surveyor, can remedy it.

The non-attendance and opposition of the village authorities, Gomashtas, and people generally, and the consequent detriment to a survey is a most serious evil. Every subterfuge is used to delay proceedings, consequently innumerable complaints are made by the Ameens, which are met with counter charges of extortion and corruption on the part of land owners, the investigation of such cases forming a very pretty item in the day's labors of a Superintending Officer. In all survey and measurement operations the very vitality and entire success of a good season's work depends, not on mere compliance only, and a tardy attention to the wants of the party, but to an *immediate*

Obstruction
to due progress.

and *ready* co-operation with them. The demands for attendance *to-day*, when the survey approaches a certain spot, are vitiated if not responded to for a week or fortnight, by that time the advantage is lost, and most likely the necessity no longer exists. In the Professional Survey particularly this is much felt, scientific operations cannot stop, expensive establishments must advance, and show a certain amount of work at the end of the month, and by the time a village authority thinks proper to do the very little that is asked of him, the survey in all probability is some miles in advance. For this cause an Ameen is tied down to a single village the greater part of the season, and it is most difficult to estimate the progress of the Khusrah, or to calculate on having the whole of the villages which have been included in the Professional, completed by the Ameens.

The notice of the authorities and of the Government has constantly been drawn to this subject, and a new enactment has now been published, which, though it does not go far enough for the cure of the evil, still supplies a partial remedy, which it is hoped will have some good effect. Act No. XX. of 1848, "for better enforcing the attendance of proprietors and farmers of land before Collectors of Land Revenue in the Lower Provinces of the Bengal Presidency," authorizes the infliction of a daily fine, not exceeding in any case 50 rupees, on any farmer or proprietor who shall refuse to attend, or cause his agent to attend, when duly summoned, and the amount of such fine accruing due, from time to time, may be levied without further confirmation by the same process as is prescribed for the recovery of arrears of revenue. Every such fine, and the amount levied, from time to time, being reported to the Commissioner of Revenue, and to whom appeal is open in the usual manner, such appeal not to prevent the levying of any fine so imposed, pending the appeal. Hitherto, before a fine could be levied, the tedious proceeding of

Attendance of
Landowners how
enforced.

obtaining the Commissioner's confirmation had to be gone through, and by the time this was done the business perhaps was concluded, consequently such fines were seldom if ever upheld, and the imposition became an empty form. It is to be hoped that the present law is not put into the hands of the executive for mere show or form, but that it may be brought into play effectually and instantly where necessary, so that the serious loss of time to Surveyors and consequent increased cost and expense to Government, may in a measure be avoided. When once an example is made in a Pergunnah or District, no further difficulty is experienced, and all parties are saved a great deal of annoyance and extra labor. The Revenue Surveyors in Bengal are all vested with the powers of a Deputy Collector under Regulation IX. of 1833, with a view of giving them some weight and importance in their several districts. These powers are not often required to be put in force in consequence of the presence of the Settlement Officer, but still, in cases of contempt, not involving a case of resistance, a fine may be levied, and in minor cases penal powers can be exercised under Section 21, Regulation IV. of 1793, Section 6, Regulation XII. of 1825, and Clause 3, Section 23, Regulation VII. of 1822, imprisonment in the civil jail for a period not exceeding 6 months, being the alternative in default of payment of fine, under Clause 7, Section 45, Regulation XXIII. of 1814.

The number of Khusrah Ameens generally employed on the Bengal Surveys varies from 100 to 150 according to the strength of the Professional Establishment, and the average number of villages requiring the detailed measurement. There is, however, no fixed limit, it being in the power of the Surveyor to apply as many men as the nature and progress of his work demands, and the rate of payment being solely by contract for the quantity actually measured, it is of no consequence, as to the exact number entertained. It is ne-

cessary always to have plenty of these men who are able to conduct their duties systematically, and in strict accordance with the orders laid down for them, and to train and instruct others who may always be ready to be enlisted in the service. Ameens are generally to be found and are easily taught, though good and trustworthy ones are not quite so easy of attainment. Each Ameen generally is obliged to employ one or more *mohurrurs*, (writers) and after a season or two, these men become experienced and fully qualified to undertake measurements themselves. Thus a full complement is always kept up, and spare men available on every emergency, and as a survey is extended from one district to another the Ameens are taken on, with the rest of the Establishment.

In unsettled districts the proper number of Ameens necessary to keep pace with the Professional Survey also depends very much on the nature of the tenures, and is always fluctuating. If the settlement is to be made *ryutwarry* then every separate field under a separate cultivator (*ryut*) must be defined, and the proceedings become very tedious and voluminous, but if the agreements are to be made only with the maliks, talookdars or proprietors, the record of estates only is sufficient, and an Ameen can in the latter instance make infinitely greater progress. Much depends on the humour of the Zemindars, if they will readily afford assistance, the Ameen can get through his work in half the time it otherwise takes him; some Ameens will remain the whole season in a moderate sized village, whilst others will complete ten times the area in the same time. There are so many things to facilitate or retard progress, that it is next to impossible to make any effectual provision to establish an uniform rate of work, and for this reason a contract payment only can be resorted to, there is no limit to the sum drawn for under this head, and it is not included in the fixed annual maximum. The steam, therefore, must be put on according to circumstances at the discretion of

the Surveyor, so as to meet the exigencies of the operations.

The first great object is always to keep the two combined operations of Khusrah and Professional well up to or abreast of each other, it being necessary that the Khusrah should coincide with the Scientific Survey, as nearly as the means employed will admit. Such a result cannot be more effectually attained than by making the two operations proceed *simultaneously* under one and the same guidance—in fact this is a *sine qua non*—and for this reason the Surveyor is the proper person to superintend and control all the proceedings relative to measurements, as in like manner the Civil Officer is for all questions and duties of a revenue character. In the North-Western Provinces, this was invariably the case, while the quality of the soil and record of the crops rested on the responsibility of the Settlement Officer. If the operations are under different management, it is evident *simultaneous* progress cannot be expected. The Settlement Officer is either in advance, or in arrears of the Professional Survey, and if the work is carried on without reference to the Surveyor, the probable chances are that the same lands are not measured, the Thaks or marks erected in the field from the lapse of time, are not found, and thus discrepancies are engendered, which will cause extreme difficulty and delay in reconciling, and where identity between the two operations does not exist, the matter remains a contested point between the Surveyor and Settlement Officer, the former has perfect confidence in his work, and the latter, knowing the impracticability of making Ameens re-measure, or even re-investigate their work, believes that he is equally as near the truth—thus constant correspondence between the two offices gives rise to serious delay and incessant annoyances. On the other hand, if the Ameen is on the spot, as he invariably ought to be when the boundary of the village is professionally surveyed, and

Combined operations how to proceed.

before the marks and pillars have been removed or washed away, he is at once made acquainted with the correct limits of his work, and by co-operating with the Assistant Surveyor can compare his exterior boundary, and rectify any errors, which he may chance to perceive between the marks on the ground, and the Thakbust Sketch Map as furnished by the Settlement Officer. For the check on the Khusrah to be in the smallest degree effectual, it must be *prompt*, the delay of a year or a season in this respect will prove *fatal* to the value of the measurement.

By these means the records are compared *at once*, and thus by mutual assistance, both parties proceed with confidence, and the first step towards accuracy is attained. The Professional Maps and Registers are all dependant on the Khusrah Returns, and by the preparation of these, in his own office, the Surveyor is enabled to complete and lodge each season's work during the recess, a point of the utmost importance to accuracy and fair progress; and on commencing a fresh field season his time and attention is not distracted by arrears and an inconvenient excess of office documents, to move about with in the district. By an absence of this due and speedy comparison of the two operations, both are left in doubt and distrusted by the local Officers, and upon this bare fact, the survey of whole districts have been recommended for revision, entailing immense expense, as well as confusion in the records, and anxiety and vexation to both Zemindars and Surveyors. It is in vain to expect a large body of Ameens to be kept in check *except by the presence of a Professional Survey*, and by the knowledge that detection of misconduct is certain, through *some* of the agencies at the command of a Professional Surveyor.

CHAPTER III.

ON THE COST OF THE KHUSRAH.

The following Table exhibits the general average cost of the Khusrah measurement, including the Purfall Office Establishment, and proportion of European Superintendence on 15 completed Surveys in Bengal—from the year 1839 to 1849.

Table exhibiting the average Cost of Khusrah Work on Fifteen completed Districts in Behar and Bengal.

Season completed.	Name of District.	Extent in Square Miles.	Average rate per Square Mile.			Remarks.
			Rs.	As.	P.	
1839	Jynteeah,	247-30	29	15	0	Maps by Scale and Compass.
1841	Balasure,	886-54	34	7	2	No Maps of any sort.
1841	Cuttack,	1256-59	25	2	2	Ditto.
1841	Pooree,	383-41	30	1	6	Ditto.
1842	Cachar and Sylhet,	234-02	29	11	2	Maps by Scale and Compass.
1841	Tipperah,	66-45	48	0	0	No Maps.
1840	Hidgelee and Tum-look,	525-02	37	1	3	Ditto.
1843	Behar,	562-18	35	5	2	Rough Eye-sketch Maps.
1842	Patna,	1157-35	23	1	9	Ditto.
1845	Sarun,	1160-00	16	14	8	Ditto.
1845	Midnapore,	756-76	31	10	9	No Maps.
1848	Monghyr,	843-50	21	7	5	Rough Eye-sketch Maps.
1848	Purneah,	2494-00	29	7	3	Ditto.
1848	Shahabad,	313-00	19	14	4	Ditto.
1849	Tirhoot,	1679-25	15	10	11	Ditto.
	Area measured by Khusrah, in 15 completed Districts,	12565-00	28	8	6	General Average.

It must be observed that where the extent measured is greatest the expense is diminished, the cost of superintendence and *Purtall* being much the same in any case, therefore the lesser area has the greater proportion of expense thrown on it. An insight into the earnings of Ameens in each season, would, however, amply show that this class of public servants do not depend on the money they receive from the Government, and as before remarked, without bribery and corruption they could not possibly exist. Every Ameen is obliged to keep a Mohurrur and two men to drag his rope, besides generally a Peadah, a Chattah Bearer, &c.

The mode of paying Khusrah Ameens is invariably by contract; fees at the rate of about two rupees for every hundred acres of land under cultivation in Bengal, are paid as soon as the measurement of the village is passed and approved of, and one rupee for the same quantity of jungle or waste. This sum includes the paper and every expense necessary for the production of a fairly written and intelligible record, which, eventually, is filed in the Collector's Office. This rate of payment, however, is somewhat higher than that observed in the North-Western Provinces, where the remuneration was not more than one rupee for a hundred acres of cultivation and eight annas for waste. The difference, however, between the two Provinces is great: in one the fields are small and complex, requiring much nicety; in the other the tenures are large, and easily and speedily measured. Ameens being paid only for work performed in the field it is their object to remain out as long as possible, but 8 months out of the 12 is the utmost that can be made available for such work. During the recess therefore it is most difficult to keep this class of men in attendance at the office, and if possible miscellaneous employment should be found for them, such as the preparation of the *Khatteeawoonee*, by which a subsistence allowance may be earned.

Measuring
Ameens how paid.

Hindoos of the Kyut caste are always to be preferred for this duty; and all Hindoos before Mussulmen, which latter class of men never seem able to compete either in accuracy, intelligence, or even honesty with their Hindoo brethren, it is therefore customary always to entertain men of the latter caste. Generally speaking they are respectable, well dressed and intelligent, and carry much weight with them on entering a village, assuming great consequence, and summoning the village authorities to attend them with a great deal of parade and show. The retainers of an Ameen are very considerable, and he never appears out without a bearer holding a chattah (umbrella) over his head.

In some Districts the Khusrah is carried on very badly, no sketch maps are given, and the Ameen's file when prepared, is but a dark and doubtful document indeed. If there is any large discrepancy in the area, it is impossible to know from what causes arising, as orders for re-investigations in the field are seldom, if ever obeyed, by an Ameen, and if re-measured produce no satisfactory result. Revenue Surveyors cannot be too particular in looking after their Khusrah work, as on its correctness depends the entire value which the local civil authorities place on the survey generally, and great discredit would attach to any Surveyor, whose Professional Survey should be revised owing to discrepancies being detected between it and the Khusrah. Ameens require the most rigorous surveillance, and without a severity and control such as European energy of character alone understands how to enforce, without, in fact, they are watched and checked with an iron hand, the utmost difficulty will be experienced in proving their measurements, and making them coincide with the Professional area. Security should always be taken on the entertainment of Ameens for their good conduct and attendance, and no work is paid for until approved and passed.

Caste of Natives
preferable for
Ameens.

To obviate as much as possible the difficulties attending the supervision of Ameens, the following rules for their management, should be attended to, as far as practicable, and the local peculiarities of a District will permit.

1st. Khusrah Ameens should be nominated to villages in such a way that they must be present when the Professional boundary survey is laid down—and their personal attendance to witness this important operation, ought to be insisted on, under penalty for non-compliance, a sufficient number of men being always kept up for this purpose.

Standing Rules
for the guidance
of Ameens.

2nd. Any unusual detention of the measurement papers in the hands of the Ameen after the work is done, must be guarded against. As much as is done monthly, weekly, or even daily, if practicable, should be lodged in the Surveyor's Office, and constant enquiry must be made to prevent Ameens leaving the scene of their labors for their own homes, before their papers are finally submitted.

3rd. No Ameen should be employed who is unable to produce a tolerable field map (Shujreh) or sketch of his measurement, exhibiting every field and delineating the exterior boundary, and who cannot give good tangible security for his attendance and good behaviour.

4th. No Ameen to be nominated to two villages at once. As soon as the records of one are lodged in the office it will be ample time to give him more work.

5th. Any Ameen who is constantly complaining of the conduct of Zemindars, raises an unusual number of disputes and remains in a village any unreasonable period, without furnishing his measurement, should be removed. Such petitions, although often well grounded, are more frequently based on motives of private pique and revenge, or to suit their own purposes, and throwing the entire responsibility on the Ameen, is the only effectual way of putting a stop to it.

6. When an Ameen is detected in committing fraud, the case should be immediately made over to the local judicial authority. In Establishments composed of 150 to 200 Ameen's the chances of detection and proof are so slight, that when a case occurs, an example of the offender is absolutely essential.

7. Having procured the local linear measuring rod or rope of the district, every precaution should be taken to guard against the Ameen's using any other. The length of this rod or rope is to be carefully recorded in British feet and inches on the fly leaf of every *Khusrah*, as well as on the Professional village plans, and ought also to be made known by *istehar* throughout the district, no other measuring implement but an *iron chain* of the correct length, should now be on any account used.

8. The native method of measuring and calculating areas, being limited to rectangular figures, all very irregular, or uneven sided figures, should be avoided as much as possible; where such shaped holdings really exist, the measurement should be divided into separate parcels and recorded under the remarks so that the error of the entire field may be reduced within the smallest limits. Ameen's to save themselves trouble are in the habit of making their fields as large as possible.*

Irregular pieces of waste land, and watercourses, site of village, &c., running in the centre of the village circuit, may be seen on all the specimens of *Shujreh's* of the old surveys, but the recorded area must be far from the truth, neither is it possible to construct a map from such measurements.

9. Each Ameen's measurement must be confined to the actual village circuit as laid down Professionally and by Takh-

* *Definition of a field.*—"A field is a parcel of land lying in one spot in the occupation of one cultivator, held under one title, and generally known by some name in the village. The Surveyor should be careful not to show two fields as one, nor to divide one field into two. The Ameen's are exceedingly apt to fall into the first of these errors, as it enables them to get over more work, and consequently to earn more in the course of the day whenever they work upon contract."—*Instructions to Settlement Officers, N. W. P., para. 24.*

bust. All intermixed lands of other villages or estates found within that circuit to be included in the record under a distinct head, but all detached and distant lands, belonging to the village under measurement, not to be sought after, or cared for, such parcels and portions of land being duly taken up, with the village in which they are actually situated.

10. Full instructions to be embodied in a *dustur-ool-oomul* perwanah (written standing orders) to be given to every Ameen prior to his deputation on any measurement, and which perwanah should be copied out in the Ameen's own handwriting, to ensure the contents being, at all events, read, and as a proof that he *can* write well.

11. In the fair copy of the Khusrah, no erasures or blots of ink to be permitted, and the country paper on which the document is written should be prepared with a solution of *Tootia-Metha* and *Neem-putta*,* (articles procurable in all bazaars) as a protection against the ravages of insects. The field map or Shujreh should be on English paper of a durable texture, as they cannot be replaced if lost or destroyed, without repairing to the spot to construct another.

12. The fees for the performance of the measurement, not to be paid until the work has been compared and found to be correct in every respect, and all the papers in which corrections and alterations may have been made have been duly replaced by fair copies, properly compared *and* attested.

13. The areas of the Professional Survey to be carefully concealed from the Ameens, and native Omlah of the office, and Sub-Assistants to be interdicted from furnishing such information either in the field or during the recess. Ameens are very liable to *make up* their total areas to agree with the Professional, and by putting in infinitely small corrections over a vast number of fields, have the means of producing an approximate result.

* "Tootia," Sulphate of Copper, Blue stone, "Metha," Fenugreek (*Trigonella Fœnum-græcum*). "Neem Putta," Leaf of the Neem Tree (*Melia Semper Virens*.)

In many districts there will be found a superabundance of jungle and waste lands inconvenient or impracticable to measure by Khusrah, and which also on the score of expense it is unadvisable to permit the Ameen to interfere with. When a village circuit contains a very large proportion of such land, the existence of which is always ascertained by the Professional Boundary Surveyor, the cultivated portion of the village should be divided off into a separate circuit by the interior detail Surveyor so as to permit the area to be calculated by triangulation on the map, and only so much given to the Ameen for a comparison, of whose work therefore a distinct area is found by the Professional operations. The jungle thus forming a circuit of itself, its area can either be added to the Khusrah misl in the aggregate from the Professional Survey, or a note can be made by the Ameen that it has been omitted in his proceedings. By this method considerable expense is saved in the Khusrah operations, and the accuracy of the area of the cultivated portion, really measured, by an Ameen, is not vitiated by the insertion of the area of such pieces of waste and jungle which it is well known a native Ameen *cannot*, and will not actually measure in the field, but invariably enters it by guess. The small additional labor with the Professional Survey is therefore, in all respects, the preferable course to pursue. Of all things, forged measurement papers are the most to be deprecated and guarded against, whilst an offence of this nature should always be visited with the severest punishment, the temptation should never be put in an Ameen's way, and if a large portion of a village circuit is reported to consist of jungle or waste land, immediate steps should be taken to relieve him of the measurement of it. The difficulty of obtaining any assistance from zemindars to clear jungle land, is quite sufficient excuse for the Ameen to make, and it is generally set forth pretty strongly, and not without justice. On the other hand, where merely

Disposal of tracts
of waste and jungle.

small patches of waste are scattered about a village circuit, intervening with the cultivated parts, they should invariably be included in the Khusrah, for the sake of the comparison of the total area of the village with the Professional, as without this check, it is most unlikely that the Ameen will be at all cautious, or be swayed by a wholesome dread of detection in any malpractices he may have in contemplation.

CHAPTER IV.

ON A NEW AND IMPROVED MODE OF CONDUCTING THE KHUSRAH.

HAVING given the usual mode of native measurements as carried on throughout the North-Western Provinces and Bengal, we proceed to notice an improved and very superior system introduced of late years in some of the Eastern Districts, and which, for accuracy and general usefulness, far surpasses the rude and antiquated specimens which in our own experience we have seen, and had good cause to deplore.

It is obvious that a heavy file of papers in the vernacular, containing the detailed specifications of a village, comprising perhaps 1,000 to 1,500 fields, without a map, or merely a rough ideal sketch made without reference to scale and compass, must at the best be a doubtful document, and in spite of the strictest Purfall, or check in the field, *may* contain many inaccuracies, and elude the vigilance of Office examiners. To obviate such doubts and uncertainties, and to place this native process of measuring land on a better comparison with English conceived ideas, the Ameens in the districts of Sylhet, Jynteah, and Cachar have been taught the use of the compass, and to conduct their measurements, and enter them in the Field-book in such a way, that a *bonâ fide* map, by scale and protractor, may be made from it, not only by themselves, but by any other person unacquainted with the field duties, at any subsequent time.

The class of natives usually employed as Ameens in India, are proverbially shrewd, intelligent men, and have a good *eye* for surveying, and many rise to be practical Surveyors, and use even a Theodolite with facility and correctness. The art therefore of taking a bearing with the very simple compass which is here described is very speedily learnt, and an instrument quite sufficient for the purpose may be made up in any bazaar in India for about three or four rupees.

The diagram, page 113, represents an instrument of similar construction, an open round box made of brass from 3 to 5 inches in diameter, and half an inch deep with two upright pieces, screwed on perpendicularly, and exactly opposite to each other. In the centre of the box, a pivot of steel finely pointed, is fixed, on which the magnetic needle freely revolves. The needle must be made of steel, the North end being well distinguished by an arrow, and a small brass cap of a conical form (agates not being procurable) in the centre, to rest on the pivot. Inside the compass box, a slight ledge is necessary to hold the glass, over which a thin ring of brass removable at pleasure fits tightly, to secure it from falling off. Underneath the compass box, a common socket of about an inch long is fixed, for fitting on to the tripod stand, on the top of which it must turn freely, with a small clamp screw to prevent the instrument falling off when carried from one station to another.

A paper dial divided into degrees from 1° to 360° , which is easily constructed with a common protractor, with the figures marked in the *vernacular* character, is fixed to the bottom of the compass box, care being taken to make the division of 360° coincide exactly with the hair sight vane—and consequently 180° with the eye vane. The degrees must be numbered round the circle from zero towards the left, and the cardinal points inverted, the result of which is, that in turning the compass in any direction, the figures underneath the North end of the needle indicate the correct magnetic bearing of the object, and the observer has only to read off.

The needle must be properly magnetised, for which purpose a common horseshoe magnet which may be procurable in Calcutta, for a few rupees, ought to be provided by the Surveyor, and this will enable him to keep as many needles as he likes in good order—care, however, should be taken never to entrust this magnet in the hands of a Native, who being unacquainted with its properties, would be sure to employ the negative and positive points, to the wrong end of the needle, and thus render the compass unfit for all practical purposes and likewise injure the magnet.*

A simple tripod stand of any seasoned wood is also easily made up by any bazaar carpenter. The circular pieces of glass to fit over the compass box, may be difficult sometimes to obtain, glaziers and diamonds not being plentiful in India, but by sending a paper pattern to the nearest large town or city, a supply can generally be found, and spare glasses should always be kept ready to replace breakages.†

It must not, however, be imagined that this roughly constructed instrument above described, is the best that can be found, or that by proper application through the Government authorities, better ones are not to be had. In the Government instrument maker's department in Calcutta, the best workmanship and best

* On the first introduction of this system, the compasses were nothing more than mere *blocks of wood*, hollowed out to receive the needle with brass uprights for sights, and these rough instruments costing a mere trifle (less than a rupee), did effectual service for some time, until they were superceded by the brass and more durable ones above described.

† A very simple expedient for cutting glass, though perhaps but little known, may here be recorded with advantage. By taking any piece of glass, such as a broken pane out of a window, and a pair of good sized scissors, and placing both hands well under cold water, in a large *chillumchee* or brass basin, the glass may be cut round and round until the proper size is obtained. The only care that is requisite, is to keep both the glass and the scissors *completely under the water*, and to clip the glass very gradually, so as not to cut off too large a piece at a time. In this way many compasses have been rendered serviceable out in the jungles, and Ameens kept at their work, when otherwise delay and inconvenience must have arisen.

materials are procurable, and surveying compasses are made up, fit for this purpose, equal to any that come from England. These, however, are expensive articles, and where such numbers are required, economy should be considered. It is, moreover, the object of these pages to show the readiest and easiest practical method, of turning the means at hand, to the best account. Surveyors should never be at a loss for an expedient, and situated as they are frequently, and indeed generally, in unknown parts of this vast empire, an ingenious mind, ever ready to make shift with such advantages as present themselves, will be the surest road to success.

Being provided with a compass of this simple construction and having learnt the manner of reading off, and taking bearings, the Ameen commences to measure the *exterior* fields of the village, that is, all the fields extending round the boundary—as shown in the accompanying map Plate XV. For each field two bearings are taken, one for the length and another for the breadth, with occasionally a diagonal observation for the better connecting link between the several fields, and to ensure greater accuracy in the mapping, and also to enable the observer to take all his bearings from one station. In the Khusrah Fieldbook, separate columns are given for this “*station bearing*,” and “*distance*” as it is called, by which means it is not confused with the quantities required as multipliers for the contents of a field. The bearings are inserted in the following form, which only differs slightly from the form before given at page 583.

For the boundary work, columns 11 and 12, as well as 7 and 9, are therefore merely required for the due protraction of the fields on the map, whilst 8 and 10, in addition to their use for this purpose, are alone required for the area of the fields, to give the contents for column 13. For the record of the measurement of the fields in the interior of the circuit, columns 7, 9, 11 and 12 are entirely omitted, the fields being put together from their respective linear values.

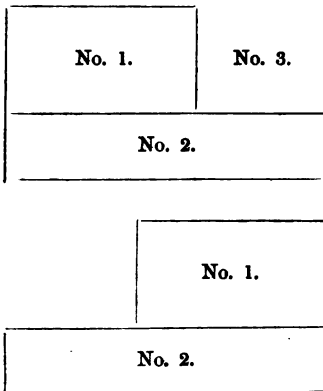
FORM OF KHUSRAH FIELDBOOK. (No. 1.—COMPASS JURREB.)

Mooza Dollyermutty, Pergumak Chottol, District Jynteah.

This Village is measured with a Bamboo null of 16 Dustedarree Hathas, or 25 Feet, 1½ Inches English measure. By Rajkiahur Khur, Amceen.

No. of Station.	Number of Dagh or Field and its Starting place.	Number and name of Talook or Towje.	Former nature of Tenure.	Name of Measuradar or Proprietor.	Name of Jotedar or Cultivator.	Bearing of Length.	Measure of Length in Nulls.	Bearing of Breadth.	Measure of Breadth in Nulls.	Station Bearing.	Station Distance in Nulls.	Contents.	Description of Soil.	Crops.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
1	No. 1. commenced East of Condrakes Nud-dee and Mooza Seebnugur, ...	No. 212 Sur-puadee Sikkidar,	In the Rajah's time, this was Ryuttee land.	Jatrapal, Son of Sonarampal,	The Possessor,.....	186°	W. 9 E. 10	120°	N. 11 S. 11	186°	9	K. K. P. 0 0 2	1st Quality,	Bheet, or Garden.
2	0	0	0	0	0	0	0	0	0	120	14	0		
3	No. 2. North of same Nud-dee, commenced from South-East corner of No. 1 Field, ...	Ditto,	Ditto,	Rampal, Son of Kettee Mundul,	Ditto,	108	N. 5 S. 5	13	E. 2 W. 1	108	5	0 0 1½	Ditto,	Ditto.
4	No. 3. North of same Nud-dee, commenced from South-East corner of No. 2,	Ditto,	Ditto,	Jatrapal, Son of Sonarampal,	Ditto,	97	N. 7 S. 7	10	E. 2 W. 2	97	7	0 1 1	Ditto,	Ditto.
5	No. 4. North of same Nud-dee, commenced from South-East corner of No. 3,	Ditto,	Ditto,	Ditto,	Ditto,	97	N. 7 S. 7	11	E. 2½ W. 2½	97	7	1 ½	Waste, ...	Gopant.

In the usual method of measurement, each field is merely recorded as lying to the North, South, East or West of the preceding ones, and frequently even this is omitted, but this is not sufficient to ensure a large number of fields plotting accurately within a circuit laid down by compass. Although the fields are for the most part rectangular, still they are to be found of various admeasurements and to enable the map to be made by any other person than the Ameen himself, who possesses a local knowledge of the disposition of the fields, and sketches them in on his map at the time, it is essential to have a defined *starting point* for the measurement of each field: thus it is recorded in the Khusrah that field No. 2, commences,



from the *South-West corner* of No. 1, and No. 3, from the *North-East corner* of No. 2, and in this expression of the *corner starting point*, lies the whole secret of the system. If this is not observed, the relative positions of Nos. 1 and 2 fields may be inverted as shown in the diagram, and the whole disposition of the fields of the entire village thrown out; in fact, the Khusrah Fieldbook

defies all attempts to reduce it to an intelligible map.

The *circuit* having thus been effected, all the interior fields are laid down merely with the rod or rope in the usual way, but still preserving the *corner* system, without any further aid from the compass, and by plotting the circuit of exterior fields according to their magnetic bearings, the interior details are found to fit in very accurately indeed. The first or rough plot of course will always show defects, but all errors are thus recorded on the first protraction, as in Plate XV., and brought to the Ameen's notice, and after he has put them to rights by re-in-

vestigation in the field and filed his answer, the necessary corrections are made on the map, which will then bear the closest comparison with the Professional one, as regards the inflections of the boundary, the distribution of details of cultivation, waste, nullahs and roads, &c., as well as area, and it is by these means that a Surveyor is enabled to check with the utmost nicety all inaccuracies in the Khusrah measurement, and at the same time satisfies himself that the large mass of vernacular papers brought in by his Ameens are trustworthy, and *bond fide* contain what they pretend to do.

It must not be supposed that the Ameen is able to make the bearings of large village circuits close without error by such means, the enormous number of observations, to say nothing of the very roughly constructed compass, and rude measuring implements, forbid this. The village is subdivided into convenient small circuits of 150 to 200 acres, round each of which the bearings are taken, and thus the error in filling in the very large number of fields, is diminished and compressed within reasonable limits.

One very desirable object in this method is to place the Khusrah Fieldbook, in such a form, that any other person, who may have had no local knowledge and no intercourse with the Ameens, is capable of protracting the fields, and constructing the map, by which, every inaccuracy in the Fieldbook is brought to light and corrected. Thus not only the bearings of each circuit and the several linear measurements are tested, but many other discrepancies regarding quality, area, possession, &c. are prominently brought to notice and at once rectified.

The circuit and the fields in the interior of the circuit, must be protracted *separately* in the first instance, as from inaccuracies of the circuit bearings and various other defects of measurement and notation of the cardinal points in the Khusrah Fieldbook they cannot be expected to fit in precisely, but after all the defects both of circuit and interior field

measurement have been adjusted, the fair map is then put together. A proportional scale, 3 or 4 times larger than that used for the Professional maps, is employed, either of 12 or 16 inches to the mile, (equal to 5 chains to the inch,) which is large enough to show the smallest holdings. The Plate No. XV. exhibits the precise method of constructing this Khusrah map, and the explanatory notes thereon, account for each step in the work. The map when completed has the several items of waste, nullahs, roads, village site, &c., colored, and shows the limits and extent of each interlaced and separate mehal. It then bears a perfect resemblance with the map of the Professional Survey with which it is compared, and identified in all its particulars, and by means of a pair of proportional compasses, the most satisfactory check is established, and no doubt can then exist of the true boundary having been adopted by both parties. By the same means also, the interior details may be taken from the Khusrah map, and reduced on to the Professional one, with sufficient accuracy, and thus save a very considerable expense for carrying on this part of the work by Professional means.

The fair colored Khusrah map may either be attached to the Fieldbook, or formed up into Pergunnahwarry volumes, for better preservation, and then made over to the Civil Authority, and by the aid of such records, not only is a settlement effected with great facility and convenience, but subsequent suits in the Civil Courts are rendered at once intelligible and easy of adjustment. In fact, in a country where the settlement is made ryutwarry, it is difficult to understand how the assessment can be fairly levied, and the rights of the numberless cultivators preserved, without something of this kind.

The expense of this method of Khusrah must next be considered. The work is done by contract, and the rates are nearly the same, as in other districts varying from 2 rupees 8 annas to 2 rupees 12 annas per 100 acres for cultivated land, and 12 annas to 1 rupee for the same quantity of waste, and

when the extra labor of the system, and the very small size of the tenures in the Bengal districts is considered, this remuneration must be acknowledged to be very inadequate. The only difference consists in the salaries of the "Nucksha Nuvees" or mappers, who are employed in the Office, and receive from 10 to 20 rupees per mensem, but with this extra expense, the general average of the Khusrah work thus performed in Jynteah and Sylhet, as exhibited in the Table in page 598, forms a very good comparison with the 15 districts therein enumerated; in fact, the cost is lower than 6 of these districts, in none of which do the Civil Authorities possess any authentic Khusrah map, beyond the common rough sketch made by the Ameen himself in the field, and who in so doing, of course, takes care to make up his map, whether his Field-book is right or wrong.

The expense of the "Nucksha Nuvees" also is balanced in a great measure by the duties they perform as Purfallers, and the good and efficient aid they render in this way, more than compensates the amount of their salaries. A practised Nucksha Nuvees will protract 150 fields in a day, and this quantity has generally been done where the holdings were particularly intricate and small, but with inexperienced hands and beginners 100 fields is as much as can reasonably be expected per diem.

The great difficulty in placing this system on an efficient footing, is the procurement of qualified Ameens and Nucksha Nuvees. But Ameens who are expert, as the generality of them undoubtedly are, and have been shown to be capable of producing eye-sketches of their measurements with wonderful accuracy, and approach to the identical shape of the village, may soon be taught. The most intelligent Ameens should be first instructed in the use of the compass, and to construct his own map on any given scale. After a few good men become expert (and which they soon will do if the Surveyor *personally* labors in their behalf, and is not above

teaching them himself,) others may be placed under them, and thus in a single season, by a little judicious management, a very fair beginning may be made. If each district Surveyor obtained the services of even *one* experienced Nucksha Nuvees, the method would soon be introduced, and made perfectly intelligible to the understandings of Ameens of the commonest calibre. The adoption of the system on all the surveys in Bengal, it is believed, is now insisted on by the authorities.

Regarding the *advantages* of this system of Khusrah, no reasonable doubt can be entertained, combining as it does, every property of the old zemindary method, with the addition of a little English science, by which a nearer approach to accuracy is attainable, and deception and fraud detected. The rudest people of a district can easily understand the Ameen's proceedings and accompany him, for the purpose of taking a copy of the measurement of the fields, even if the addition of the bearing be unintelligible. In Jynteah and Cachar, where it was first introduced, the inhabitants were alike unused to British rule or customs, but in no instance was the progress of the Ameens, interrupted by violence, or pretended dislike to the operations.

These advantages may be summed up in the following manner :—

1st. The admirable check and comparison afforded and consequent superior accuracy of the work.

2nd. The ability of any second or third party ignorant of the locality, and without connivance with the measuring Ameen, or help of any sketch or map, to produce a fair protraction from the misl or file.

3rd. The thorough insight thereby given to the voluminous Khusrah misl, and immediate detection of all errors clerical or venal.

4th. The great benefit to the Surveyor or Superintending Officer who thus obtains the utmost confidence in his work, and is saved infinite trouble, annoyance and doubt.

5th. The value to the Government in possessing a really useful and permanent record combining the qualities of the Professional map, with the addition of the minutest detailed specifications of property in the village, fit for every purpose both fiscal and judicial.

6th. Its comparative inexpensive cost when viewed with the lasting value of its results.

The great desideratum of a superior method of Khusrah than what is at present carried on in most districts, cannot be too strongly impressed on the notice of Surveyors. The benefit to the State, as well as the great comfort to himself in having a fair and intelligible measurement record, which can be rendered useful hereafter and amenable to scrutiny and check at the time, must be obvious to any person who has had experience in such matters. In Bengal, especially where it is almost an impossibility to show the different estates on the maps of the Professional Survey, it is absolutely essential to produce Khusrah maps on such an extended scale, as we have above described, which will delineate every estate on the rent roll, however intermixed or confused. The system that we are advocating, is the only one applicable for such purposes, it is at once *efficient* and *economical*, and is eminently calculated to effect every object, if properly conducted. It also affords the readiest means of carrying out the provisions of Act No. IX. of 1847, "*regarding the Assessment of Lands gained from the Sea or from Rivers by alluvion or dereliction within the Provinces of Bengal, Behar and Orissa.*"*

* Clause 3. "And it is hereby enacted, that within the said Provinces it shall be lawful for the Government of Bengal in all districts or parts of districts of which a Revenue Survey may have been or may hereafter be completed and approved by Government, to direct from time to time, *whenever ten years from the approval of any such survey shall have expired*, a new survey of lands on the Banks of Rivers and on the shores of the Sea, in order to ascertain the changes that may have taken place since the date of the last previous survey, and to cause new maps to be made according to such new survey."

It may be remarked, that if this system is so superior and trustworthy, the fact of its wider diffusion not having extended to other districts, is a matter of surprise. This must undoubtedly be acknowledged, and it is to be regretted that improvements in the Khusrah have not been long ere this introduced into every survey. The principle here spoken of has been made no secret on the part of those engaged in its practical application. In some Revenue Surveys the Khusrah is too apt to be regarded as a secondary and unimportant branch, and all improvements and innovations require great energy and perseverance, as well as other persuasive and conciliatory qualities on the part of the Surveyor, whose time and attention is well occupied by the scientific portion of his duties. It should, however, be remembered that the Khusrah forms the basis of all the revenue proceedings, and which alone the local authorities bring into practical use, and that the result is satisfactory and creditable to the parties employed, in proportion as the people of a district enter into their agreements, and pay up regularly the jumma assessed. A good settlement, made without much complaint and opposition on the part of landowners, assuredly reflects *great credit* on a Surveyor, who will thus obtain his reward for any trouble or pains the Khusrah may have cost him.

CHAPTER V.

ON THE LOCAL LAND MEASURES, AND MODE OF REDUCING LINEAR INTO SQUARE MEASURE.

THE calculation of the true land or square measure of the District, should be made with the greatest care, and too much precaution cannot be observed, in personally comparing the standard cubit or hath, usually given by the Collector of a District. On the relative value of the beegah, with the British Acre, depends the subsequent confirmation or rejection of all the Native measurements, therefore unless accurate Tables are formed at the commencement of operations, the utmost confusion in carrying on the office duties is likely to arise. It will then be the first duty of the Surveyor to apply for the standard *cubit, guz, luggee, hath, jurreeb, russee, rod, chain*, or whatever may be the name of the linear measuring implement in use, and ascertain what number of such lengths constitute the *side* of a beegah. The local standard, if such a thing exists, after being very carefully measured *several times over*, its value in British feet and inches must be recorded; with these two data the number of square yards in a beegah is deduced, and from thence the number of acres, roods, poles, &c. This having once been established, two Tables should immediately be drawn out, one of *beegahs* converted into *acres*, and the other of *acres* into *beegahs*. These will save an infinity of trouble, and indeed are absolutely indispensable for the ready understanding of both Europeans and Natives in a Survey Office, and to prevent error in frequently comparing the areas of the two operations.

Supposing the length of a rod furnished by the Collector of a District to be 25 feet, 1·92 inches, as ascertained by repeated trials, and the beegah to be a rectangle whose sides are 28 and 12 of these rods respectively, we shall then have $28 \times 12 = 336$ square rods in a beegah, and 25 feet, 1·92 inches $\times 12 = 301\cdot92$, which squared, gives 91155·7864 square inches in one rod. This multiplied by 336, the number of square rods in a beegah, gives 30628344·2304, the number of square inches in a beegah, which divided by 1296, the number of square inches in a square yard, gives 23632·9816 square yards or 4·8828 acres equal to 4 acres, 3 roods, 21 poles, 8 yards. Again, if the russee is found to be 80 yards exactly, and the beegah side is one russee, then the beegah will be 80×80 equals 6400 square yards, and if $4840 : 1 :: 6400 : 1\cdot322314$ the value of the beegah is therefore $1\cdot322314$ or 1 1 11 ^{sq. yds.} ^{acre.} ^{sq. yds.} ^{acres.} ^{acres.} ^{R.} ^{P.} ^{sq. yds.} 27·60.

In the North-Western Provinces, the beegah does not vary much, the *Agra* beegah of $2756\frac{1}{2}$ square yards, the beegah *side* of 52 yards, 1 foot, 6 inches, is common to many other districts such as Muttra, Allyghur, Mynpooree, Etawah, Furruckabad, &c. The *Delhi* Province beegah contains 3025 square yards, or five eighths of an acre (3 roods 5 Perches) of the standard *Ilahy guz* assumed at 33 inches, the beegah *side* being 60 guz or 165 feet or 55 yards, and this is also common to the Umballa, Khytul, Loodhianah and Ferozepore Districts, the Jullundur Dooab, as well as to the greater part of Behar. The best information extant on this subject from Prinsep's Useful Tables, is given in the Notes,* but

* The *Ilahy guz* of AKBER was intended to supersede the multiplicity of measures in use in the 16th century, and in a great degree it still maintains its position as the standard of the Upper Provinces. In general, however, different measures are employed in each trade, and the cloth merchant in particular has a distinct guz of his own. Thus the cloth guz has assimilated in many places to two haths, or one yard; and the frequent employment of English tape-measure, as well as carpenter's two-feet rules, will ere long confirm the adoption of the British standard to the exclusion of the native system, for the linear measure of articles in the bazar.

from all we are able to gather, we incline to the belief that the *general standard* spoken of by Prinsep, was never regularly introduced into the Revenue Survey of the North-Western Provinces. In addition to the two beegahs already noticed the Benares and Ghazeepore beegah of 3136 sq. yards was

The true length of the *Ilahy guz* became a subject of zealous investigation by Mr. NEWNHAM, Collector of Furruckhabad, and Major HODGSON, Surveyor General, in the year 1824, during the progress of the great Revenue Survey of the Western Provinces, when it was found to be the basis of all the records of land measurements and rents of Upper India.—As might have been expected, no data could be found for fixing the standard of AKBER with perfect accuracy; but every comparison concurred in placing it between the limits of 30 and 35 English inches; and the great majority of actual measures of land in Rohilkhund, Delhi, Agra, &c. brought it nearly to an average of 33 inches. Mr. DUNCAN, in the settlement of the Benares Province in 1795, had assumed 33·6 inches to the *Ilahy guz*, on the authority, it may be presumed, of standards in existence in the city, making the beegah = 3136 sq. yards.

The results of the different modes of determination resorted to in 1824-5, so characteristic of the rude but ingenious contrivances of the natives, are curious and worthy of being recorded. Major HODGSON made the length of the *Ilahy guz*

	Inches.
From the average measurement of 76 men's fingers' breadths,	= 31.55
From the average size of the marble slabs in the pavement of the Taj at Agra, (said to be each a <i>Shahjehany guz</i> of 42 fingers?)	= 33.58
From the side of the reservoir at the same place, called 24 guz,	= 32.54
From the circuit of the whole terrace, 532 guz?	= 35.80
Mr. NEWNHAM, from the average size of 14 char-yaree rupees, supposed to be each one finger's breadth, makes it	= 29.20
From the testimony of inhabitants of Furruckhabad,	= 31.50
From statement in the Ayeen Akbery, of the weight of the cubic guz of 72 kinds of timber, (this would require a knowledge of the weights,)	= 31.50
Mr. HALHED, from average measurement of 246 barley corns,	= 31.84
From $\frac{1}{2}$ sum of diameters of 40 Munsooree pice,	= 32.02
From $\frac{1}{2}$ of 4 human cubits measured on a string,	= 33.70
From average of copper wires returned by Tehseeldars of Moradabad as counterparts of the actual measures from which their beegahs were formed,	= 33.50
Mr. DUNCAN, as above noticed, assumed the <i>Ilahy guz</i> at Benares, ...	= 33.60
In Bareilly, Boolunshuhr, Agra, as in the following table, it is	= 32.5

actually in use. In Bengal, however, the value of the beegah varies in every District, frequently in every Pergunnah, and occasionally in very Estate or Village within the same Pergunnah. In the "Tables of Land Measure, published by order of the Sudder Board of Revenue, Lower Provinces, in 1840," there will be found no less than 218 different beegahs, or other local measures of various denominations, in 38 Districts, varying in size from one rood to 50 acres. In the single District of Midnapore there are 53 different land measures, in Jessore 20, and in Rungpore 15, and in many Districts there are at least from 6 to 10 different sorts. In the Province of Orissa, the number of measuring rods formerly were too numerous to detail, but through

It is natural to suppose that the guz adopted for measuring the land should vary on the side of excess, and probably all the above, thus derived, are too long. The Western Revenue Board, thinking so many discrepancies irreconcilable, suggested, that the settlements should everywhere be made in the local beegah, the Surveyors merely noting the *actual value of the Ilahy guz in each village* and entering the measurement also in acres; but the Government wisely determined rather to select a general standard, which should meet as far as possible the existing circumstances of the country. Thus the further prosecution of the theoretical question was abandoned, and an arbitrary value of the *Ilahy guz* was assumed at 33 inches, which was in 1825-26 ordered to be introduced in all the Revenue Survey records, with a note of the local variation therefrom on the village maps, as well as a memorandum of the measure in English acres. Mr. Sec. MACKENZIE thus describes the convenience which the adoption of this standard (sanctioned at first only as an experiment and liable to reconsideration) would afford in comparisons with English measures.

"Taking the *jureeb* (side of the square *beegah*) at 60 *guntehs*, or 60 *guz*, the *beegah* will be 3600 square *guz*, or 3025 square yards, or five-eighths of an English acre (3 roods, 5 perches). The *jureeb* will be equal to 5 chains of 11 yards, each chain being 4 *guntehs*. In those places where the *jureeb* is assumed at 54 *guz* square, it would equal 4½ chains, giving 2450½ square yards (or 2 roods, 10 perches). In either case the conversion from one to another would be simple, and the connection between the operations of the Surveyors and the measurements of the Revenue Officers would be easily perceived."

This convenient beegah of 3600 square *Ilahy guz*, or 3025 square yards, or five-eighths of an acre, may be now called the standard of the Upper Provinces. It is established also at Patna, and has been introduced in the settlements of the Sagur and Nerbudda territories.

the interference of the local authorities, one standard of 4840 square yards, equal to the British acre, was adopted, on the first introduction of survey operations, and carried throughout the three Districts of Cuttack, Pooree and Balasore, without opposition or dislike on the part of the people. The value of the measuring rod or *Puddika* being 10·4355 feet or 10 feet $5\frac{1}{3}$ inches and the side of the acre 20 of such rods.

It would appear that the Returns, furnished to the Sudder Board of Revenue, of the various land measures, are partly erroneous in some Districts, the survey of which has been completed, the beegah actually used differing with the one recorded in the Tables. In some of the local offices the standard measure is simply a matter of tradition, and when applied for, the Nazir of the Court is directed to report on the correct length of the hath or luggee—this he does with the utmost simplicity by holding up his own arm, pointing from the elbow to the tip of the little finger, sometimes adding that as he is a small made man, one, two, or four, fingers' breadth must be added on. The Collector on this gives an order for a roobocarry to be sent to the Surveyor Sahib, to the purport of the standard in use in his District being "one hath and four fingers," and the luggee or russee being so many of such lengths. This vague and uncertain information, however, should not satisfy a Surveyor. Such data for such a purpose are manifestly absurd, and yet it is daily in practice, in many Districts in the Lower Provinces where Ameens are sent out to *investigate* into special cases connected with the Civil and Judicial Courts. If a Surveyor is unable to obtain some sort of definite length for the standard measure, it should be his duty to fix and determine it, in personal communication with the Collector of Revenue. In some Districts, an iron bar, or rod, is lodged in the Collectory, indicative of the value of the cubit or hath, in which case of course the Surveyor has only to compare its length very carefully as before remarked. On the completion of a survey, the identical

measuring rod or chain should be lodged with the Collector of a District, and its exact length fully reported on for future reference. It is also most necessary to furnish a copy of the Table of Land measure as used in the Survey, and without this precaution is taken, the probable chances are that the local authorities will adopt some other measure in any subsequent investigations which they may have to make in the field, the result of which must of course be unfavorable to the records of the survey on a comparison being instituted.

Zemindars and other Village Agents have always a good deal of objection to make regarding the length of the measuring rod, and are most persevering in their efforts to prove that the one about to be brought into use, is too long or too short, or different to what the former measurement was conducted with. The object, generally, is to make the beegah larger than it ought to be, when in the event of assessment the Government Revenue may fall lighter.

The following Tables of some of the chief beegahs in use in the Upper and Lower Provinces will prove useful, and exemplify the remarks in the previous pages on the subject. From the decimal of an acre, the smaller denominations are easily obtained by multiplying by 4 and 40, and in the same way with the decimal of a beegah, by multiplying by whatever the local land measure dictates :

2756·25 Square Yards.	<i>The Agra Beegah.</i>				3025 Square Yards.	<i>The Delhi Beegah.</i>			
	Acres.	Beegahs.	Beegahs.	Acres.		Acres.	Beegahs.	Beegahs.	Acres.
1	1·7560	1	0·5694	1	1·600	1	0·625		
2	3·5120	2	1·1389	2	3·200	2	1·250		
3	5·2680	3	1·7084	3	4·800	3	1·875		
4	7·0240	4	2·2778	4	6·400	4	2·500		
5	8·7800	5	2·8473	5	8·000	5	3·125		
6	10·5360	6	3·4168	6	9·600	6	3·750		
7	12·2920	7	3·9863	7	11·200	7	4·375		
8	14·0480	8	4·5557	8	12·800	8	5·000		
9	15·8040	9	5·1252	9	14·400	9	5·625		
10	17·5600	10	5·6946	10	16·000	10	6·250		
11	19·3161	11	6·2642	11	17·600	11	6·875		

The beegah of 3025 square yards prevails also in the Districts of Patna, Shahabad, Sarun, Bhaugulpore and Monghyr. The beegah of 3136 is in common use, and peculiar to the Benares and Ghazeepore district.

3136 Square Yards.	<i>The Benares Beegah.</i>			
	Acres.	Beegahs.	Beegahs.	Acres.
	1	1·5433	1	0·6479
2	3·0867	2	1·2958	
3	4·6300	3	1·9438	
4	6·1733	4	2·5917	
5	7·7168	5	3·2396	
6	9·2601	6	3·8876	
7	10·8034	7	4·5355	
8	12·3467	8	5·1834	
9	13·8900	9	5·8313	
10	15·4333	10	6·4792	
11	16·9766	11	7·1271	

In Tirhoot and Monghyr the chief prevailing beegahs are of 4225 square yards and 3600 square yards, and the latter is also common in Sarun.

4225 Square Yards.	<i>Prevalent in parts of Tirhoot and Monghyr.</i>				3600 Square Yards.	<i>Prevalent in Sarun, Tirhoot and Monghyr.</i>			
	Acres.	Bee-gahs.	Bee-gahs.	Acres.		Acres.	Bee-gahs.	Bee-gahs.	Acres.
1	1·1455	1	0·8729	1	1·3444	1	0·7438		
2	2·2910	2	1·7458	2	2·6888	2	1·4876		
3	3·4365	3	2·6187	3	4·0332	3	2·2314		
4	4·5820	4	3·4916	4	5·3776	4	2·9752		
5	5·7275	5	4·3645	5	6·7220	5	3·7190		
6	6·8730	6	5·2374	6	8·0664	6	4·4628		
7	8·0185	7	6·1103	7	9·4108	7	5·2066		
8	9·1640	8	6·9832	8	10·7552	8	5·9504		
9	10·3095	9	7·8561	9	12·0996	9	6·6942		
10	11·4550	10	8·7290	10	13·4440	10	7·4380		
11	12·6005	11	9·5019	11	14·7884	11	8·1818		

In the Eastern part of Bengal the local measure is considerably larger and assumes a variety of denominations. In Arracan, Chittagong, Tipperah, Bulloah, Backergunge and part of Mymensing, the *Droon* varies from 5 up to 195 acres. In Dacca, Furreedpore, Jessore, Pubna and Rajeshye, the *Khada* is the prevailing measure, running from 4 to 21 acres. In Assam and part of Mymensing, the *Poorah* ranges from $1\frac{1}{4}$ in the former to 25 acres in the latter district. In Sylhet, Jynteah and Cachar, the *Koolbah* is the known measure differing between 3 and 5 acres. The Cachar koolbah equals 23313·89 square yards, that in Jynteah 23633 square yards, and for Sylhet the following Table is given, the length of the measuring *null* or rod being 21 feet $8\frac{1}{2}$ inches, and the koolbah sides 28 and 12 of such nulls :

<i>The Sylhet Koolbah.</i>				
17542·78 Square Yards.				
Acres.	Koolbahs.	Koolbahs.	Koolbahs.	Acres.
1	0·2759	1	1	3·6245
2	0·5518	2	2	7·2490
3	0·8277	3	3	10·8735
4	1·1036	4	4	14·4980
5	1·3795	5	5	18·1225
6	1·6554	6	6	21·7470
7	1·9313	7	7	25·3715
8	2·2072	8	8	28·9960
9	2·4831	9	9	32·6205
10	2·7590	10	10	36·2450
11	3·0349	11	11	39·8695

For the ready conversion of beegahs of *any* number of square yards whatever, into corresponding acres, the following Table will be found useful:

Table for finding a Multiplier to convert Beegahs, or any other local measurement, of any number of Square Yards, into corresponding Acres.

Square Yards.	Multiplier.	Square Yards.	Multiplier.	Square Yards.	Multiplier.	Square Yards.	Multiplier.	Square Yards.	Multiplier.
48·40	·01	1016·40	·21	1984·40	·41	2952·40	·61	3920·40	·81
96·80	·02	1064·80	·22	2032·80	·42	3000·80	·62	3968·80	·82
145·20	·03	1113·20	·23	2081·20	·43	3048·20	·63	4017·20	·83
193·60	·04	1161·60	·24	2129·60	·44	3097·60	·64	4065·60	·84
242·00	·05	1210·00	·25	2178·00	·45	3146·00	·65	4114·00	·85
290·40	·06	1258·40	·26	2226·40	·46	3194·40	·66	4162·40	·86
338·80	·07	1306·80	·27	2274·80	·47	3242·80	·67	4210·80	·87
387·20	·08	1355·20	·28	2323·20	·48	3291·20	·68	4259·20	·88
435·60	·09	1403·60	·29	2371·60	·49	3339·60	·69	4307·60	·89
484·00	·10	1452·00	·30	2420·00	·50	3388·00	·70	4356·00	·90
532·40	·11	1500·40	·31	2468·40	·51	3436·40	·71	4404·40	·91
580·80	·12	1548·80	·32	2516·80	·52	3484·80	·72	4452·80	·92
629·20	·13	1597·20	·33	2565·20	·53	3533·20	·73	4501·20	·93
677·60	·14	1645·60	·34	2613·60	·54	3581·60	·74	4549·60	·94
726·00	·15	1694·00	·35	2662·00	·55	3630·00	·75	4598·00	·95
774·40	·16	1742·40	·36	2710·40	·56	3678·40	·76	4646·40	·96
822·80	·17	1790·80	·37	2758·80	·57	3726·80	·77	4694·80	·97
871·20	·18	1839·20	·38	2807·20	·58	3775·20	·78	4743·20	·98
919·60	·19	1887·60	·39	2855·60	·59	3823·60	·79	4791·60	·99
968·00	·20	1936·00	·40	2904·00	·60	3872·00	·80	4840·00	1·00

RULE.—Take out from the column containing the Square Yards the nearest number to those contained in the Beegah, opposite which will be found its Multiplier, the difference wanting to complete the number of Square Yards in the Beegah, will then be taken out with its Multiplier and added to the former, and so on, until the actual number of Square Yards contained in the Beegah are extracted. The sum of these will give the Multiplier required.

NOTE.—In taking out any number of Square Yards less than 48·40, it is only necessary to remove the decimal point as many places to the left hand in the column of Square Yards as the number may be required, removing the points also as many places in the column of Multiplier.

EXAMPLE.

Required the Decimal Multiplier for a beegah containing 1600 square yards.	
Square Yards,	1600
Next nearest in Table,.....	1597·20 ·33
	2·80 ·00058
	Sum ·33058

Therefore the beegah of 1,600 square yards equals ·33058 of an acre.

The multiplicity of the local measures in the Lower Provinces and the excessive confusion and inconvenience felt thereby, has at last however produced its own cure. When an evil is at its zenith, there is some hope of amendment; by a Circular Order of the Sudder Board of Revenue, dated the 23rd November 1849, the whole system has been broken down, and one uniform value given to the beegah for all the Districts subject to the Board's jurisdiction, and to be used in all measurements carried on for the future, under their superintendence. The standard adopted is that of the puckha Calcutta beegah, of 14,400 square feet, or 1600 square yards. The acre therefore is equivalent to 3·025 of such beegahs. It is not apparent on what principle or investigation this beegah has been assumed, differing so greatly as it does with all the local measures in Bengal Proper, as before shewn; and it is to be regretted that whilst so great an innovation was in contemplation, either the British acre of 4840 square yards was not at once introduced, as was the case in Orissa, or a beegah bearing some simple ratio to it, as has been done in the Delhi and other North-Western Provinces. The standard *Ilahy guz* of 33 inches being now more widely established in British India than any other local measure of length, every thing possible should be done to extirpate the use of other measures not easily comparable with it; and all local land measures should be founded on some simple multiple of this standard, such as the Gunter's chain, which is the basis of the acre: no round number of yards can be introduced into such a system without retaining the inconvenient number 11 as a multiplier or divisor.

The *yard* therefore ought to be wholly discarded from our Indian system of measures, and every thing referred to the *Ilahy guz* of 33 inches, or some multiple or submultiple of it, such as a *hath* of $16\frac{1}{2}$ inches. Any beegah founded on either of these measures may be readily compared with the Gunter's chain of 66 feet, and through it with the English acre. It would have been preferable to this to have established the Bengal beegah, so that one acre might be equivalent to 3 beegahs, rather than 3.025 beegahs, although a *Square Beegah* of this value cannot be obtained. The *Hath* of $16\frac{1}{2}$ inches which may be the basis of this beegah, and of its subdivisions the *cottah* and *chittack*, is *half* the *Ilahy guz*; and the two beegahs of Delhi and Bengal would be so easily comparable with each other, as to facilitate the process of adopting hereafter some land measure that would include both, if that should be thought desirable. But it is of far less importance that the *land* measures of two distant countries should be identical, than the measures of *length* should be so. An uniform standard, whatever its size, is however of the greatest possible advantage and utility, and cannot be too highly appreciated.

The new beegah side is exactly 120 feet, or 80 haths, which squared, gives 14,400 feet or 1,600 square yards. The following will therefore be the relative values of the beegah and acre respectively.

<i>The Bengal Standard Beegah.</i>				
1600 Square Yards.	Acres.	Beegahs.	Beegahs.	Acres.
	1	3.025	1	0.33058
2	6.050	2	0.66116	
3	9.075	3	0.99174	
4	12.100	4	1.32232	
5	15.125	5	1.65290	
6	18.150	6	1.98348	
7	21.175	7	2.31406	
8	24.200	8	2.64464	
9	27.225	9	2.97522	
10	30.250	10	3.30580	
11	33.275	11	3.63638	

Of the lower denominations, 20 cottahs make one beegah, and 16 chittacks make one cottah; additional tables for the conversion of roods and perches into cottahs and chittacks will be found in the Appendix, being too bulky for this place.

To adapt a convenient scale for this beegah, which shall be proportional with the one used for the Professional Survey, take the following:

Khusrah and Thak-
bust Scale.

Professional Survey, take the following :

Professional scale of 4 inches = 1 mile = 80 Gunter's chains.			
and 1 inch, or 20 chains = 1320 feet.			
	Russee.	Haths.	Feet.
Then	1 =	80 =	120
and	11 =		1320

therefore 11 russees are equivalent to 1 inch or 20 Gunter's chains on the same scale, and by increasing the scale 4 times 11 russees = 4 inches. By dividing 4 inches therefore into 11 equal parts, each will be equal to a russee or beegah side of 120 feet, and the quarter of such division or 30 feet, will represent the chains actually employed, *two* of which squared or 60 feet \times 60 feet equal 3600 feet or 5 cottahs. This scale will therefore be 330 feet or $2\frac{3}{4}$ beegahs to the inch, or 16 inches to the mile. The Khusrah measurements performed with such chains, and protracted on such a scale, will bear precisely the ratio of 4 to 1, to the Professional maps.*

* The local Square Measure will be as follows:

	Feet.	Sq. Feet.
$\frac{1}{2}$ of a Chain \times $\frac{1}{10}$ of a Chain	or 6 \times 12	= 9 = 1 Cowrie.
4 Cowries or $\frac{1}{2}$ of a Chain \times $\frac{1}{2}$	or 6 \times 6	= 36 = 1 Gundah.
20 Gundahs or 4 Chains \times $\frac{1}{2}$	or 120 \times 6	} = { 720 = 1 Cottah.
or 1 Chain \times $\frac{1}{2}$	or 30 \times 24	
20 Cottahs or 4 Chains \times 4 Chains	or 120 \times 120	} = { 14400 = 1 Beegah.
or 1 Chain \times 16	or 30 \times 480	

CHAPTER VI.

ON THE ORTHOGRAPHY OF NATIVE NAMES,—GENERAL STATISTICS,—GEOGRAPHICAL, REVENUE AND AGRICULTURAL REPORTS.

ONE of the most difficult subjects with which Europeans in this country have to deal, is the intelligible conversion of the vernacular into the English character, and it will be readily admitted, that Surveyors of all persons must be the most interested and concerned in following such a good system, that any person knowing the original and the substituted character, should be able to convert the one into the other without difficulty, and that the names of places so romanized on the geographical maps of the country should be at once recognizable and familiar to the ear. In a work like this, it may be expected that some fixed rules should be laid down for the guidance of the department, but any fixed system, is easier to propose, than to find followers for. As regards spelling, some people are quite incorrigible, we shall endeavour however to place on record the prevailing methods heretofore existing in the great Trigonometrical as well as Revenue Surveys, together with such remarks on other systems as appear to be called for.

Sir Wm. Jones's method is at once elegant and phonical, and has found complete acceptance with learned and scientific men, it is therefore, with some slight modification, in use in the Great Trigonometrical Survey of India. The rules followed in this department are very simple and may be thus stated :

1st. All vowels have the Italian sound, as in Sir Wm. Jones's rule; no others to be used.

2nd. The semi-vowels to be used only as consonants, such as *Y* in *Yaholi*.

3rd. All consonants have their ordinary sound, but express the harsh sound of *C* by *K* and the soft sound by *S* whereby *C*, as an independent letter, becomes expunged.

4th. Express the soft sound of *G* universally by *J*, reserving the former of these letters in all cases to denote the harsh sound only.

5th. Dispense with the reduplication of consonants, as much as possible, because long words are an evil on maps.

6th. Drop superfluous letters of all kinds, wherever they are so weak as to make it a matter of doubt whether they ought to be pronounced or not. Example *Hydrabad*, *Sikandrabad*, &c. wherein some persons introduce a short vowel between the *d* and *r*, and others do not.

7th. The old established orthography of historical names should not be interfered with, as they have become settled and familiar by long use, and it would be pedantic and presumptuous to alter them, and the same idea would not be conveyed. Thus write *Meerut* not *Mirat*, *Hydrabad* not *Haiderabad*, or *Huederabad* (according to Gilchrist,) *Beder*, not *Bidar*, *Calcutta* not *Kalkata*, *Captain* not *Kaptan*, *Cawn-poor* not *Kánpúr*, *Allahabad*, &c.

8th. Double consonants should never be used when single ones will answer, thus *Ph* instead of *F* is not advisable, as in *Filaor* not *Phillore*, neither *Ch* instead of *K*, although there is Italian authority for the latter.

This method is doubtless a phonical one, well adapted for general use, and scientific men will not agree to any deviation from Sir Wm. Jones; but, however learned Surveyors may be, the persons into whose hands their maps fall, may be very ignorant Englishmen, and it is extremely doubt-

In the Revenue Survey Department, Gilchrist's method has generally been employed, although no definite rules appear to have been laid down on this important subject. Like any other system whatever, if rigidly carried out it is intelligible enough to those who have learned and practised it, but it has never found acceptance with the learned or scientific. It looks ugly and adopts all the bad pronunciation of English. No other nation, but the English, ever give *u* the short sound of *but*. This is a fundamental assumption of Gilchrist's, and ruins the whole of his system, the chief merit of which is, the undeviating tenacity with which he adheres to it under all difficulties.

In the directions for Settlement Officers, promulgated under the authority of the Hon'ble the Lieutenant Governor North-Western Provinces, there is another alphabet proposed to be used in the conversion of names from the languages of the country into English. Transposing from one language to another by this method is easy, and it is particularly well adapted for the services, and having gained some footing, and being recognised by all the Settlement and other Revenue Officers, the Surveyors who have to follow their steps, and depend on their enquiries, are obliged in a great measure to resort to the same phraseology, and hence the more scientific, but more difficult system of Jones, has never been followed by this branch of the Survey of India.

The following is the alphabet exemplified :

Alphabet proposed to be used in the conversion of names from the languages of the Country into English.

1 A.	a.	Atmanugur,	..... आ	८१
		Ahunpoor,	.....
		* Ahunpoor,	....
2 B.	b.	Bareepoor,	..... व	८२
3 B.H,	b.h, ...	Bhooneepoor,	..... भ	८३
4 C.H. C.H,H.	ch, ch,h.	Chichura,	..... चछ	८४ ८
		Chhipagurh,	.....

5 D.	<i>d.</i>	Dâk Bazar,	डद	د
		Datanugur,		
6 D,H.	<i>d,h.</i>	Dhurumpoor,	ठध	دهه
7 E.	<i>e,</i>	Ekeesghur,	ऐ	
8 E.E.	<i>e.e.</i>	Eshwurnugur,	ई	ای عی
		Esalpoor, Edgurh, ...		
9 F.	<i>f.</i>	Fureedpoor,		ف
10 G.	<i>g.</i>	Gunga Sagur,	ग	ک
11 G,H. GH.	<i>g,h. gh...</i>	Ghur Mookhtesur, ...	घ	غ گھ
		Ghazeepoor,		
12 H.	<i>h.</i>	Huveleeshuhur,	ह	ح هه ه
		Hat,h gaon,		
		Hurjinspoor,		
13 L	<i>i.</i>	Iradutgunge,	ई	ع
		Indurgurh,		
		* Ilum bazar,		
14 J.	<i>j.</i>	Jynugur, Jahilgurh,...	ज	ج
15 J,H.	<i>j,h.</i>	Jheel, Jharundeh, ...	झ	جهه
16 K.	<i>k.</i>	Kunkerpoor,	क	ک
		Kako Deh,		
17 K,H. KH,	<i>k,h. kh,.</i>	K,hurukpoor,	ख	خ
		Khalisnugur,		
18 L.	<i>l</i>	Lalgurh,	ल	ل
19 M.	<i>m.</i>	Mahinutabad,	म	م
20 N.	<i>n.</i>	Nurayunpoor, ...	नडजयंग	ن
21 O.	<i>o.</i>	Omedgaon,	ओ	او آ
		Olanugur,		
22 O.O.	<i>o.o.</i> ...	Ooudes,	उऊ	ار ا
		Oostadpoor.		
23 O.U.	<i>o.u.</i> ...	Oushandeh,	औ	او
24 P.	<i>p.</i>	Peepulgaon,	प	پ
25 P,H.	<i>p,h.</i> ...	Phoolnugur,	फ	پهه
26 Q.	<i>q.</i>	Qasimgunj,		ق

27 R.R,H.	<i>r,r,h.</i> ...	Rungpoor,	.....	चरडठ	र
		Rhotas,	.....	
28 S.	<i>s.</i>	Sareeram,	.....	स	س
		Sa * dutgunj,	.....	वश	ش
29 S.H.	<i>s,h.</i>	Sholapoor,	.....	
		Shureef bazar,	.....	
30 T.	<i>t.</i>	Tunk hadah,	.....	त	ت
31 T,H.	<i>t,h.</i> ...	Thanagurh,	.....	थ	ته
32 U.	<i>u.</i>	Umretpoor,	.....	अ	ع
		* Uleepoor, Ullahabad,			
33 V.W.	<i>v,w.</i> ...	Wustabad,	.....	व व	و
		Vizeerpoor,	.....	
34 Y.	<i>y.</i>	Yarpoo, Yuabzar,	... ऐ		اي عي
		Yy * shnugur,	.....	
35 Z,ZH.	<i>z,zh.</i> ...	Zeeafutabad,	.....		ز ذ
		Zalimpoor, &c.,	.....		ظ ژ

The English alphabet having no letter capable of representing the ع Ain of the Persian, the use of this as contradistinguished from A. E. I. or U. may be indicated by a mark thus * before or over the letter.

The importance of statistical information is now universally felt and acknowledged, and the Revenue Survey Department, as might be expected, from the peculiar facilities at its disposal for the attainment of such information, during the progress of Survey operations in every remote part and corner of the country, is not behind-hand in rendering good and valuable service to this branch of scientific enquiry. The attention of Revenue Surveyors is particularly and urgently directed to this point by the Circular Orders of the department, and the Annual Returns are not deemed complete without a full and succinct account, geographical and statistical, of every pergunnah of

the district under survey. The Court of Directors in their despatch No. 6 of 1846, dated the 3rd June, which has been printed and circulated for general guidance, lay particular stress on the great practical importance of this duty, and on the advantage which may be expected from the transmission home of such information as to local details, which *so many of their servants* cannot fail to possess. The heads of information, most desirable to be collected, are likewise detailed in this despatch which includes also full and particular instructions as to the mode of collecting the same, and enjoins the most rigid accuracy as to matters of fact, without which all statistics would be worse than useless, tending only to mislead.*

In the directions for Settlement Officers, North-Western Provinces, para. 41, it is specially noted that the Surveyors are to give returns of population, wells, and ploughs, and the mode of recording this and other useful information for every village coming under survey, is shewn in the register Plate VIII. This, together with descriptive remarks as to the state of prosperity, trade, distribution of the land, &c., furnishes the groundwork for the pergunnah statement, and the general district report. In unsettled provinces where an assessment follows the survey, and a Khusrah measurement is universal, the statistical enquiries are pursued by the Ameen and recorded in the Vernacular with his Khusrah Fieldbook, and from the length of time every village must be occupied by this Officer for the purpose of prosecuting the measurement, the time and means at his disposal, are very considerable for eliciting the required details. These, however, are checked again by the Purtall Ameen and by the Supervising Officer in comparison with lists (*Khaneh Shumareh*) demanded and

* For some valuable information, useful alike to the Surveyor or Settlement Officer, *vide* a Paper in volume No. 164, Journal of the Asiatic Society of Bengal. By James Alexander, Esq. B. C. S. "On the Tenures and Fiscal relations of the Owners and Occupants of the soil in Bengal, Behar and Orissa."

obtained from the village authorities, and the investigations of Putwarries and others. The Settlement Officer again has numerous opportunities for testing these returns at the time of assessment. It may therefore be inferred that the information thus gleaned, is as worthy of confidence, as could be expected, and no difficulty whatever exists in procuring it, if rightly and fairly sought for on the part of the Ameens. The character however of these men, and the cloak made of the power in their hands to extort money from the people, should induce great caution in receiving their statements, or of entrusting any additional powers in their hands beyond what is absolutely essential.

In the Bengal and Behar Provinces, where the Khusrah measurement is only partial, and not more than from 15 to 20 per cent. of the villages are visited by the Ameens, the mode of prosecuting statistical enquiries must be through other agency. The demarcation establishments are here brought into use for this purpose, and the assistants, employed in the interior professional detail survey, may be made available; and whatever difficulties arise, they can alone be overcome by the intelligence, activity, and ability of the Officer in charge of the survey.

The following comprise the heads of information, all or a portion of which, may be reported on with advantage; and annexed is a tabular statement extracted from an actual report made by the late talented Officer whose name it bears, and which may be copied with safety.

LAND.—Geographical position, Extent.

Boundaries, Divisions, Subdivisions.

Climate, Aspect, Superficial configuration, Mountains, Hills.

Geological structure, Mines, and Minerals.*

Forests, jungle, &c. Plains, soil and productions, modes of cultivation.

* *Vide* "Desiderata for the Museum of Economic Geology of India" in the Appendix.

Prices of principal products.

Tenure and occupation, Modes and rates of assessment.

Labor employed and its remuneration.

WATER.—Navigable rivers.

Description, and length of.

How far navigable.

Origin and source.

Banks, and soil of bed.

Vessels employed on them.

Shoals, velocity.

LAKES.—Description and situation.

Height above the sea.

CANALS.—Their purposes.

Length and depth.

Vessels employed on them.

Cost and return on the outlay.

Wells, pukka and kutchra, tanks, &c.

Means of irrigation.

CITIES.—Towns and villages.

Situation and general description.

Number of houses and whether pukka or kutchra.

General caste of inhabitants.

Remarkable buildings, Temples, Shewallahs, Mundérs, Durgahs
or Mosques.

Public establishments.

Thannahs, Tuhseeldarees, Moonsiffes.

Police, Custom, and Salt Chowkees.

Schools, Churches.

POPULATION.—Census of people of different caste.

Agricultural and Non-Agricultural, Average number per Square
Mile.

Employment.

Condition and Physical constitution.

Health and disease.

WEALTH.—Education, and method of pursuing it.

Charitable institutions not educational.

State of litigation and of crimes.

Police, number, remuneration and efficiency.

COMMERCE.—Manufactures.

Capital employed.

Weights and Measures, Coins.

Modes of transit and communication.

By land, high and metalled roads, passes and dofiles, kutchra cart
roads, footpaths.

By water.

Impediments and their duration.

Fords, ferries, and bridges.

Fisheries.

Postal arrangements.

Taxation.

Sources of revenue and produce of each tax.

Mode of collection.

Fairs and markets.

History and antiquity, facts illustrative of early or more recent history, and changes political or agricultural.

Factories, indigo, sugar, saltpetre, silk.

Golaha, Salt.

Agricultural implements.

AGRICULTURAL INDUSTRY.—Ploughs, domestic animals.

Cattle, draft and grazing.

Buffaloes, &c.

Wild sports.

Wild animals.

In the Memoir on the Statistics of the North-Western Provinces, compiled under the order of the Hon^{ble} the Lieutenant Governor and published in 1848, it is stated that the late settlement of those provinces has provided many statistical facts which it has been the aim of that Government to bring together and place on record with precision, and that in order to create greater confidence in the correctness of the revised statistical return, the memoir was compiled, so as to place permanently on record the mode in which the information was collected, and the authority on which each of the facts rests. In this work much valuable instruction is afforded, and we have extracted some of the leading rules for a fair enumeration of the people, or of houses.* The statistical return of the

* Para. 14. "In such census it will only be necessary to separate the people into the classes mentioned in the Table. Separation into males and females, of boys and girls, is useless, because these classes will not be accurately reported, nor will the distinctions be uniformly observed."

15. "All persons who derive their subsistence, in whole or in part, from the land, whether in the form of wages or rent, should be shown as cultivators, even though they may have other sources of income."

1842, by Robert Wroughton, Captain, Revenue Surveyor.

STATISTICS.

Total.	Population.		Total months.		Public Establishments.		Fairs & Markets.	
	Mahomedans.		Males.	Females.	Males.	Females.	Number of Rats held in the Year.	Number of Rats held in the week.
	Hindoos.	Males.							Females.
328	728	653	0	0	1369	1	1	
366	994	960	0	0	1954	1	1	
2087	5346	4429	18	18	9811	31	4	
205	459	403	0	0	862	1	1	
1243	3018	2570	0	0	5886	5	1	
787	1866	1805	8	4	3683	2	1	
976	2300	1970	0	0	4270	6	1	
1596	3794	3494	46	48	7382	1	1	
1631	3619	3227	8	5	6859	18	2	
0239	22120	18491	80	75	41766	77	13	

Population, 1623

as 14 to 9 amongst the Hindoos; and 16 to 15 amongst the Mahomedans; on

6 divisions comprising 32 districts, gives 322 as the average number of persons to the British statute mile, and 1.99 as the number of acres to each person. This is a high average population and it has consequently been received with some doubt and suspicion, from the comparative statements of other countries. China, universally considered one of the most densely populated countries, is only 277 to the square mile, according to "Davis's China" census of 1812, and the only European country approaching to this Indian average is Belgium, which is 392, on the Geographical mile of 847 acres, equivalent to 296 on the statute mile of 640 acres, but as stated in the memoir "there is good reason to suppose that

16. "Any census based on actual enumeration of the people will probably be vexatious and erroneous. It will be better to rest the calculation on the number of houses or families."

17. "A house or family must be defined according to its local signification; perhaps it may generally be defined as a family living together, inhabiting a distinct part of a tenement, or the whole of one or more tenements, in the same enclosure."

18. "The number of houses or families being thus ascertained, the number of persons actually resident in a certain number of such houses may be counted, and the average may be applied to the whole. The value of the result will depend upon the care and the discrimination with which this is done."

19. "The enumeration should take place in those houses or villages where the object of the process is most likely to be understood, and where the co-operation of the zemindars and other influential inhabitants can be secured."

20. "Distinct averages should be assumed for different classes of the inhabitants. Thus the average in cities or towns may be different from what it is in villages, the average in pukka houses from that in cutcha houses, the average in one purgunnah, from that in another; in Mahomedan families from that in Hindoo families, or Brahmin or Rajpoot families, from that in Chumar or Passee families."

21. "The returns when given in by the Tuhseeldars should be tested by the Collector. This is easily effected when the details are given Mouzahwar, for if the returns for a few Mouzahs taken indiscriminately are found to be correct, the whole may be assumed to be so."

22. "The following general rules may be found useful in judging of the accuracy of returns regarding population."

23. "The average number of persons to a house or family is between 4 and 5. From peculiar circumstances, in certain localities, it may fall below or rise above this standard."

the averages in the well-peopled parts of India are higher than in the most populous countries of Europe;—” and so it would decidedly appear not only from the results published in this memoir but from the subsequent researches made in Behar and Bengal, as the progress of the Revenue Survey advances, all of which tend to keep up a high estimate. The insertion here of the population of the North-Western districts may serve as a guide, we have therefore extracted such columns from the printed return. At the same time, the discrepancies between the averages of many of the Districts in this Statement are still so large as to leave considerable room for further doubt, Azimghur, Jounpore, and Ghazee-pore being nearly *double* of Allahabad and several other Districts and larger than Agra or Dehlie. The general average, however, (322 per square mile) is *one-third* lower than that taken in 1826 (484 per square mile) and commented on in para. 17 of the Court’s Despatch.

24. “The average number of persons to a square geographical mile of 847·2

* Belgium,	392
British Isles,	220
France,	208
Saxony,	314
Wirttemberg,	266
Tuscany,	302
Sweden,	22
Norway,	11
Russia Proper,	36
Europe,	80

Taken from the Map of Europe—published by the Society for the Diffusion of Useful Knowledge.

from boyhood.” *Vide* Memoir on Statistics, pages 8 and 9.

Para. 3. “The definition of a house or family, and the grounds on which the number of souls to a house or family is stated, requires to be very carefully examined, and the mode as well as the result of the examination to be fully stated.”

4. “Care does not seem to be generally taken in discriminating between the agricultural and non-agricultural classes. On referring to para. 15 of the former printed Circular, you will observe that *the members of all families who derive their support or any part of their income from the cultivation of land are to be entered as agricultural, whether or not they actually hold the plough or personally conduct the usual agricultural operations.*” *Vide* Memoir on Statistics, page 14.

acres, in the chief countries in Europe, is given in the margin.* There is good reason that the averages in the well-peopled parts of India are higher than in the most populous countries of Europe.”

25. “The number of adult females is found to be in excess of that of adult males, but the number of boys is much larger than of girls. The cause of this, in some measure is, that females are considered to have passed from girlhood at an earlier age than males

Revised Statistical Return of Area and Population in the Districts of the North-Western Provinces prepared in 1848.

Divisions.	Districts.	Area in Square Miles of 640 Acres each.	Population.				Total.	Number of Persons to each Square British Statute Mile of 640 Acres each.	Number of Acres to each person.
			Hindoo.		Mahomedan, and others not Hindoo.				
			Agricultural.	Non-Agricultural.	Agricultural.	Non-Agricultural.			
Delhlie.	Paneeput,	1279.9	125593	60601	24781	72445	283420	221.4	2.68
	Hurreeanah, ...	3300.8	154674	21346	37484	11632	225086	68.2	9.38
	Dehlie,	602.5	85448	129066	9227	82809	306550	508.8	1.25
	Rohtuck,	1340.9	150572	81541	16720	45286	294119	219.3	2.92
	Goorgaon,	1942.3	176328	105180	109792	69026	460326	237.0	2.70
Meerut.	Seharunpore, ...	2165.4	273543	62971	139907	70632	547353	252.8	2.53
	Mozuffernugur,	1617.0	172304	218341	61445	85504	537594	331.8	1.93
	Meerut,	2332.9	329133	327704	62976	140923	860736	368.9	1.73
	Boolundshur,	1855.1	309237	261614	44061	84481	699393	377.0	1.69
Rohtcund.	Allygurh,	2149.2	315642	336150	21880	65684	739356	344.0	1.86
	Bijnour,	1904.0	225049	190515	44348	180639	620546	325.9	1.96
	Moradabad, ...	2967.3	438387	232064	170024	168867	997362	336.0	1.90
	Budaon,	2368.4	557797	154270	57344	56301	825712	348.7	1.83
	Bareilly and Pillibheet, }	2937.7	668074	215721	113594	146268	1143657	389.3	1.64
	Shahjehanpore, }	2463.3	436166	124420	134520	117462	812568	327.3	1.95
	Muttra,	1607.1	349065	299627	14066	39890	701688	436.6	1.46
Agra.	Agra,	1860.8	466313	276350	17686	67871	828220	445.0	1.44
	Furruckabad, ...	1909.8	514529	238895	34792	66583	854799	447.6	1.43
	Mynpoorie,	2009.0	441002	158987	13700	26120	639809	318.5	2.01
	Etawah,	1674.6	284638	170524	4691	21171	461224	287.3	2.23
Allahabad.	Cawnpore,	2337.0	565240	353038	18211	56533	968031	424.9	1.51
	Futtehpore, ...	1583.3	263194	197267	21776	28895	511132	322.8	1.98
	Humeerpore and Calpee, }	2240.5	299558	120125	10223	22185	452091	201.8	3.17
	Banda,	2878.8	375777	142309	16007	18433	552526	191.3	3.33
	Allahabad,	2901.1	496839	177684	48273	47017	710263	253.6	2.52
Benares.	Goruckpore, ...	7346.5	1779678	331247	198765	66843	2376533	323.5	1.97
	Azimghur,	2520.3	915431	241602	70646	86271	1313950	521.3	1.23
	Jounpore,	1552.2	563078	156753	30620	49052	798503	514.4	1.24
	Mirzapore,	5244.8	425689	357058	11113	37528	831388	158.5	4.03
	Benares,	994.5	356026	320024	5662	59714	741426	745.5	0.86
	Ghazeepore, ...	2187.4	673743	271676	31548	82320	1059287	464.3	1.32
	Grand Total, ...	71985.4	13127956	6324690	1596277	2150745	23109668	322.3	1.99

In the first few Districts which came under survey in these Provinces, Statistical enquiries were unfortunately omitted, and as no settlement follows the survey, the deficiency has not been made good; neither in those Districts where the information has been collected can the results be so satisfactory and trustworthy as in the North-West Provinces, where double and treble investigations have been prosecuted. For the sake of completeness and comparison of the data given for different Districts, it is to be hoped that the subject will not be lost sight of, but that it may be prosecuted in the same manner as described in the Memoir on the North-West Provinces. The following table exhibits all the details at present procurable for the Lower Provinces, distinguishing those Districts, which have actually come under investigation by the Revenue Survey, taken either by an actual census in some Districts, or by the enumeration of houses, and estimate of a certain number of souls per house, checked by another estimate drawn from the land under cultivation in some instances.* In several of

Bengal and Be-
har Statistics.

* The only manner that I have of calculating the population is from the extent of cultivation, which is of course liable to great error. Two calculations may be founded on this basis.

First, it will appear in my account of the agriculture of this district, that about 4,80,000 ploughs are required, and one man is the usual allowance for each plough. The men employed in actual agriculture cannot therefore be less than 4,80,000, and these, I imagine, will be nearly one-fifth of their families, including old people and children, which will make the agricultural population 2,40,000. Now considering the very imperfect state of agriculture, and the rudeness of the arts in this district, I do not think that we can add more than one-fourth of this number for all the other classes of society, especially as a quantity of grain is exported. This will give 3,00,000 for the total population, being about 558 persons for each square mile (on an area of 5,374 square miles).—Secondly, an estimate may be formed from the quantity of produce; and rice being the chief food of the people we may consider that alone. The total quantity of rough rice, after deducting seed, that I have calculated to be annually raised in this district, is about 36,800,000 muns, which according to the trials that I made, will give 27,650,000 muns of clean rice. Now I have supposed, that to the value of 3,200,000 Rupees of rice, or

the Districts, however, the calculation is based only on partial areas, comprising certain Pergunnahs, yielding a certain average, and this number has been again assumed for the entire District. The average, on the 14 Districts so collected, amounts to 246 per square mile, and the average deducible from the Population Returns, given in the *Agra Guide* and *Gazetteer* on nine other Districts, is 198 per square mile, the general average on the entire area of 74,264 square miles being 219 per square mile, and which approximates closely with the estimate made in 1822, as noticed by the Court of Directors, viz. 243 per square mile, on an area of about double of what is here given. This calculation, although roughly made, seems entitled to some confidence. It does not embrace the populous cities of Calcutta, Dacca or Moorshedabad, or the thickly-populated Districts of Hooghly, Kishnagur, Baraset, &c., but until the whole country has been carefully and minutely explored, and much more labor and pains expended than have heretofore been devoted to this interesting and useful science, it will be in vain to expect absolute accuracy.

4,400,000 muns are exported, and there will remain for consumption 23,250,000 muns Calcutta weight. Then, allowing half a seer of 96 Sicca weight for each person daily, which is the calculation usually made in this district, this quantity of rice will feed more than 4,000,000 of people; considerable deductions however must be allowed for grain that is wasted, distilled, consumed by fire, eaten by cattle, and used in the arts; but still this population seems to be exaggerated, and the calculation founded on the number of ploughs seems more suitable to reality.—“*Historical Description of Dinagepur District, by Buchanan (Hamilton), Book 2, Page 67.*”

Returns of Population of the undermentioned Districts of Bengal and Behar, derived from the Records of the Revenue Survey, the Bengal Guide, and Gazetteer, and other sources.

No.	Districts.	Area in Square Miles.	Return of Population derived from the Records of the Revenue Survey.		Approximate Return of Population derived from the Bengal Guide and Gazetteer and other Sources of Districts which have not come under enquiry during the progress of the Revenue Survey.		Remarks.	
			Number of Houses.	Average Number of souls per Sq. Mile.	Total Population.	Average Number of souls per Sq. Mile.		
1	Pooree,	2687	106916	232	<p>Census taken of population on the entire district. On the average population of 31 Pergunnahs by a census actually taken. On an examination of the houses in 13 Pergunnahs at 4 per house. Ditto ditto. On the average population of 3 Pergunnahs checked on the estimate of land under cultivation assuming that 5 acres will support a family of 6 souls. Census taken of population. On examination of houses assuming 4 souls per house. Ditto ditto at 5 souls per house. On examination of houses of 22 Pergunnahs at 4 per house. On ditto at 4 per house. On ditto at 2½ per house.</p> <p>Assumed chiefly from the Chowkedaree Tax Papers, by Civil Authorities of Districts, as quoted in the Gazetteer for 1941.</p>	
2	Cuttack,	3062	220688	213	.....	.....
3	Balsore,	1876	96286	257	.....	.....
4	Midnapore,	3977	202827	204	.....	.....
5	Hidglee,	1084	36211	141	.....	.....
6	Chittagong,	2717	108925	153	.....	.....
7	Sylhet, (part of)	114	21134	246	.....	.....
8	Jynteeah,	459	36605	255	.....	.....
9	Cochar,	650	32579	39121	.....	.....
10	Patna,	1828	127874	509466	.....	.....
11	Tirhoot,	6109	326609	1683045	.....	.....
12	Purneeah,	5703	460368	1961532	.....	.....
13	24-Pergunnahs, (part of)	1800	171000	684000	.....	.....
14	Maldah,	1131	162552	281380	.....	.....
15	Sarun,	6894	.....	251	.....	.....
16	Shahabad,	4403	.....	973873	.....	.....
17	Behar,	5694	.....	199004	.....	.....
18	Rajshabee,	2812	.....	1000000	.....	.....
19	Rungpore,	4563	.....	885000	.....	.....
20	Dacca,	4726	.....	121480	.....	.....
21	Mymensingh,	7000	.....	1152215	.....	.....
22	Jessore,	3363	.....	1624183	.....	.....
23	Burdwan,	2112	.....	968000	.....	.....
24	Burdwan,	2112	.....	500000	.....	.....
	Total,	74284	2130089	8182592	24646	814104		General Average 219.84 per Square Mile.

Part V.

PRACTICAL ASTRONOMY, AND ITS APPLICATION TO SURVEYING.

CHAPTER I.

DEFINITIONS.

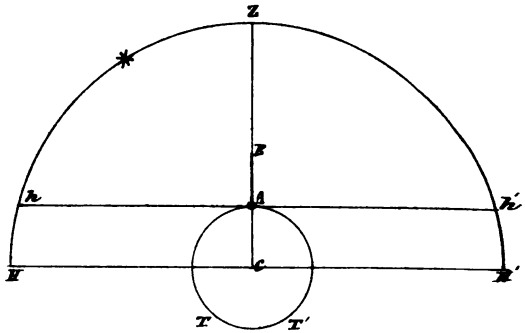
SUPPOSE a plummet to be freely suspended from a given height, it will fall perpendicularly upon the surface of a pool of stagnant water, for there is no reason to believe that it should be more inclined to one side than to another.

Now, conceive the line wherewith the plummet is hung to be produced to the heavens, it will cut a point there, which is called the zenith.

Again, if the surface of the stagnant water be imagined to be extended as far as the heavens, it will form a plane, which, with reference to a spectator placed where the plummet was supposed to be suspended, will divide the visible from the invisible part of the heavens. This plane is called the sensible horizon.

Again, conceive another plane to be drawn through the centre of the earth parallel to the sensible horizon, it will be the spectator's rational horizon or simply horizon.

In the annexed diagram ATT' represents the earth, C being its centre. Now let BA be the direction of the plummet at any point A on the earth's surface; the line AB , produced to the heavens will furnish Z the zenith. Again



the plane hAh' drawn perpendicular to the zenith line AZ , will be the sensible horizon, being coincident with the surface of the stagnant water at A ; while the plane HCH' drawn parallel thereto through the earth's centre, will be the rational horizon.

In Astronomy, all measurements made on the surface of the earth, are referred to its centre or to the rational horizon HCH' . This subject has already been adverted to at p. 155, on reference to which, it will be seen, that the correction whereby an observation is transferred to the earth's centre, is called "parallax." This parallax is always of small amount, being the angle subtended by the earth's semidiameter at the object observed. The sun, the moon, and the planets are the only celestial bodies which are liable to this correction, the stars being free from it, owing to their immense distance from the earth. In the Appendix, will be found a Table of Parallax for the Sun. Here it is only necessary to observe that it will be convenient to throw the sensible horizon out of consideration altogether, and supposing the observer or rather his eye to be placed at the earth's centre, refer the definitions of the Astronomical terms to that point at once.

To a spectator situated at the earth's centre, the heavens will appear like a sphere of which his eye will be the centre,

the stars being placed or projected on its interior surface. This being admitted, it will follow from what is said at p. 548 of this work, that the rational horizon is a great, and the sensible horizon a small circle of this celestial sphere.

Now, extend the zenith line ZA , until it meets the rational horizon HCH' . This junction would have taken place at the centre C , if the earth were a sphere. But as this, however, is not the case, (the earth being a spheroid, differing in a small degree from a sphere) the junction above adverted to, will occur at a small distance from the centre. Considering the nature of the computations which will be treated of in this treatise, no sensible error need be apprehended if the earth is taken as a sphere, and we will accordingly make this assumption, in which case it is clear, that the earth's centre C will become the site at which the zenith line AZ produced will meet the rational horizon HCH' as represented in the figure.

Suppose a plane to be drawn through the zenith line CZ and extended to the heavens, this will be a vertical plane, and there are four properties belonging to it, which are as follows:—

- 1st. It will be perpendicular to the rational horizon.
- 2nd. It will always pass through the zenith.
- 3rd. It may be drawn through any given point, and
- 4th. The figure, which it will trace on the interior surface of the celestial sphere, will be a great circle of that sphere.

A circle formed in this way, by the section of a vertical plane with the celestial sphere, is called a vertical circle.

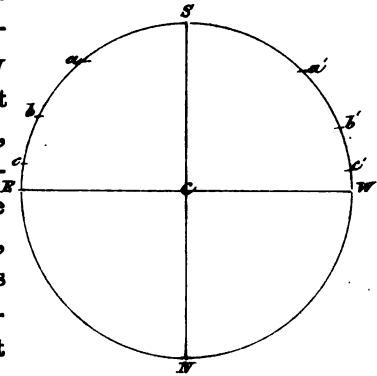
To illustrate these definitions, we will suppose that in lieu of the spectator, a theodolite is placed at the earth's centre duly levelled and adjusted. It is evident, that the azimuth circle will become coincident with the rational horizon, and that the telescope, when moved round in altitude, will describe a vertical circle in the heavens.

Altitudes and zenith distances are measured upon vertical circles. For instance, supposing a vertical circle to be drawn

through an object, its altitude will be that part of the vertical circle intercepted between it and the horizon. Again, the zenith distance of the object in question is an arc of the same vertical circle lying between it and the zenith.

The zenith being 90° from the horizon, it follows that when the altitude and the zenith distance of an object are added together, the sum will amount to a quadrant. Hence one of these elements being known, the other may be found by deducting the given term from a quadrant or 90° .

We will now attend to the phenomena of the rising and setting of stars. With this view let the annexed circle represent the plane of the rational horizon, C being its centre which is coincident with the centre of the earth. Suppose, a spectator, placed at this centre with his face turned towards South, observe a star to rise at a and set at a' . Again, let him in a similar



manner mark the points b and b' of the rising and setting of another star. Now the horizontal arcs $a a'$ and $b b'$ being bisectable at one point, let this point be S . The point S , so found, is called the South point of the horizon.

Suppose now a vertical circle to be drawn through S , it will be the meridian of the place to which the rational horizon, adverted to above, appertains. Like every other vertical circle the meridian will pass through the zenith and be perpendicular to the horizon. In addition to these properties, it will have this peculiarity, namely, that it will be the locus or the line of the greatest altitudes which stars attain to during the day.

An altitude, measured on the meridian, is called the meridional altitude, in contradistinction to altitudes observed upon other vertical circles.

As stated elsewhere, the meridian cuts the horizon at the south point or *S*. It will likewise intersect it at another point *N*, which is called the North point of the horizon.

If a vertical circle be drawn perpendicular to the meridian, it will be the prime vertical. Like the meridian the prime vertical will intersect the horizon at two points, which will be the East and West points of the horizon.

In the preceding diagram, the lines *NS* and *EW* represent the projections, the former of the meridian and the latter of the prime vertical upon the plane of the horizon; the points *N*, *S*, *E*, and *W* standing for the four cardinal points, *N* for North, *S* for South, *E* for East, and *W* for West.

The azimuth of an object is measured upon the plane of the horizon. For instance, take any star and suppose a vertical circle to pass through it, the arc of the horizon intercepted between the North and the vertical circle aforesaid, is called the star's azimuth.

“ We have spoken of the risings and settings of stars, such as they will appear to be to a spectator placed at *C*, the centre of the plane of the horizon, but hitherto we have said nothing of the intervals of time elapsed between their respective risings and settings. Now, a spectator, in the Northern climate, looking towards *S*, the South, cannot fail to remark that a star between its rising at *b* and setting at *b'* is longer above the horizon than a star which rises at *a* and sets at *a'*, which kind of inequality takes place, and in a greater degree with every star successively placed between *b* and *S*. But he may also note, that every star takes the same time in passing from its rising through its setting to its rising again. A star, therefore, at *a*, is longer below the horizon than a star at *b*, and still much longer than a star at *c*. But a star rising at *E*, the East point, has this peculiarity, namely, that it is above the horizon exactly as long as it is below. On this account, the circle in which such a star moves, is called the Equator.”*

* Woodhouse's Astronomy, Vol. I, Part I, Page 6.

The Equator, traced in the way described above, will be a great circle of the Celestial sphere, perpendicular to the meridian and cutting the horizon at the points *E* and *W*. Imagine now a line to be drawn from *C* perpendicular to the plane of the Equator, it will when produced Northward and Southward, point to the North and the South poles. This line is called the axis of the Celestial sphere.

Besides the zenith and the North and South points upon the horizon, the meridian of a place will pass through the North and South poles of the Celestial sphere.

The axis of the Celestial sphere coincides with the earth's axis of rotation. Again the planes of the terrestrial Equator and meridian as laid down at *p.* 548 when extended, will trace on the interior surface of the Celestial sphere the Equator and meridian defined in this chapter.

There are two co-ordinates required to determine the position of a star in the heavens, namely, 1st, the declination, and 2nd, the right ascension. The simplest definitions, which can be given of these terms, are as follows:—Suppose the given star to transit, or come to the meridian, then its declination will be the arc of the meridian intercepted between the star and the Equator, its right ascension being the time which would be shewn by a sidereal clock adjusted to read $\begin{matrix} \text{h.} & \text{m.} & \text{s.} \\ 0. & 0. & 0. \end{matrix}$ when the first point of Aries passed the meridian.

The first point of Aries may be determined in this way. It is well known that either on the 20th or 21st March, the day and night are equal or nearly so; or which is the same thing the sun remains as long above the horizon as below it. On the day that this equality takes place, the sun rises due East and sets due West: or in other words, it occupies a point in the Equator, which point is called the first point of Aries, the origin of all right ascensions. The first point of Aries can always be determined by computation.

Now, the declination of a star will be North or South according as the meridional arc, whereby it is measured, extends

towards the North or the South pole. When a star's declination is known, its North polar distance may be computed in this way. When the declination is South add it to 90° : When it is North, subtract it from 90° : the sum or difference so obtained will be the North polar distance required.

The horary angle of a Celestial object is the time it takes to come to the meridian or the time it has passed it.

The latitude of a place is an arc of the meridian, intercepted between the Equator and the zenith.

The longitude of a place or rather the difference of longitude between two places is an arc of the Equator intercepted between the meridians appertaining to those places.

A sidereal day is the interval elapsed between the two successive transits of a star on the same meridian. It is divided in the usual manner into hours, minutes and seconds. A clock, truly adjusted to sidereal time, will read $\begin{smallmatrix} h. & m. & s. \\ 0. & 0. & 0. \end{smallmatrix}$ when the first point of Aries passes the meridian.

In like manner, the interval included between the sun's leaving a meridian and its returning to it, is styled a solar day.

Before proceeding any further, it is necessary to shew why a solar day is greater than a sidereal day. The diurnal motion of the heavens from East to West is only apparent, arising from the real motion of the earth in a contrary direction. Suppose, now, that the sun and a star are on a meridian together on any given day. On the following day the meridian will again meet the star at the same place, but not the sun, which will have advanced about $59''$ towards the East, which arc, therefore, will require to be described by the meridian before it can reach the sun, whence it is clear, that the interval, (sidereal day) included between the transits of a star, will be less than the like interval (solar day) for the sun.

The solar day, however, cannot be made use of to regulate and adjust a clock; because on account of the variable motion of the sun, it will not be of the same length throughout the

year. To remedy this inconvenience, astronomers imagine a mean sun moving in the Equator with the true sun's mean velocity in the direction of that plane, and they call the interval included between its two successive transits on the same meridian a mean solar day. This mode of reckoning time is in general use; all astronomical clocks and chronometers as well as common watches being adjusted by it. The Nautical Almanac furnishes the rules for deducing the transit of the mean sun from that of the true sun.

The foregoing are all the astronomical terms which occur in this work, and they have been defined in a way, in which it is hoped, they would be easily apprehended by a practical man. Before the reader, however, proceeds to the perusal of the following Chapters we would recommend him to acquire a knowledge of the Nautical Almanac by attentively reading over the explanation of the contents appended to that work.

It is of considerable importance to a Surveyor to know the names and positions of the principal stars. The following directions from "Mackay on the Longitude," will be found of service :

OF THE FIXED STARS.

The Fixed Stars are so named, because they are observed to retain their relative places with respect to each other. Some Stars appear to be of a sensible magnitude to the naked eye, but when viewed through a telescope, seem only as lucid points, without any apparent diameter; hence their immense distance from the solar system is inferred and consequently, they emit their own light, otherwise they would be invisible. It is, therefore, reasonable to suppose them to be so many suns; diffusing light and heat, to planets revolving round them.

The Stars, with respect to their apparent splendour, are divided into orders, called **MAGNITUDES**. The brightest are called Stars of the First Magnitude: the next to these in splendour, Stars of the Second Magnitude, and so on to those which are just perceptible to the naked eye, and which are called Stars of the Sixth Magnitude. Those which cannot be discerned without the assistance of a telescope, are called *Telescopic Stars*, and are divided into orders of the Seventh, Eighth, Ninth, &c. magnitudes accordingly. We are not, how

ever, to infer from this, that the Stars can be exactly reduced to one or other of these magnitudes, for the Star α Aquilæ is reckoned by some to be of the first Magnitude, and others esteem it of the second ; hence those Stars, whose Magnitudes are doubtful, are generally marked in catalogues as partaking of both Magnitudes—thus α Aquilæ is marked 1.2, signifying that it is either of the first or second, or rather between these Magnitudes ; and ν Scorpionis is marked 3.4, as being between these Magnitudes ; and the figure denoting the magnitude, to which the Star is nearest, is put first—thus, δ Scorpionis is marked 3.2 ; signifying, therefore, that it is between the second and third Magnitudes, but nearest the third. From what has been said of the Magnitudes of the Stars, we are not to suppose that their sizes are in the ratio of their apparent Magnitudes ; they may perhaps be nearly of the same bulk, but the apparent Magnitude of a Star depends on its distance.

The Stars, for the purpose of finding any one more readily, are divided into parcels called CONSTELLATIONS. These, in order to assist the imagination, are supposed to be circumscribed with some known figure, as that of a *man, woman, ship, sextant, &c.* and those Stars which lie between constellations are called UNFORMED STARS. As it would be an endless task to give a proper name to each Star, it has, therefore been customary to mark the Stars of each constellation, with the letters of the Greek alphabet, in such a manner, that the first letter is prefixed to the brightest Star, the second letter to the next in brightness, and so on. Many of the brightest of the fixed Stars have also proper names—thus α , Bootæ, is also called *Arcturus* ; ϵ , Virginia, is called *Vindemiatrix, &c.*

The celestial sphere is divided into three parts, the ZODIAC, and the NORTHERN and SOUTHERN HEMISPHERES.

The ZODIAC extends to about 8° on each side of the ecliptic, and contains the orbits of all the planets : there are twelve constellations in the Zodiac. According to the ancients, there were 21 constellations in the Northern hemisphere, and 15 in the Southern ; and consequently, 48 constellations in the Zodiac and both hemispheres. Modern astronomers, however, by curtailing several of the ancient constellations of some of their stars, which they formed into new constellations ; and by forming into constellations the unformed Stars, or those which lay between the ancient ones, have increased the number of constellations in the Northern hemisphere to upwards of 40, and those in the Southern to about 48 ; and consequently, there are upwards of 100 constellations in all. The names of these constellations are as follows :

ZODIACAL CONSTELLATIONS.

1 Aries,	The Ram.	7 Libra,	The Balance.
2 Taurus,	Bull.	8 Scorpio,	Scorpion.
3 Gemini,	Twins.	9 Sagittarius,	Archer.
4 Cancer,	Crab.	10 Capricornus,	Goat.
5 Leo,	Lion.	11 Aquarius,	Water Bearer.
6 Virgo,	Virgin.	12 Pisces,	Fishes.

NORTHERN CONSTELLATIONS.

1 Ursa Minor,	The Little Bear.	22 Triang. Borealis.	The Northern Triangle'
2 Ursa Major,	Great Bear.	23 Coma Berenices,	Berenice's Hair.
3 Draco,	Dragon.	24 Camelopardalus,	The Camelopard.
4 Cepheus,	Cepheus.	25 Monoceros,	Unicorn.
5 Bootes,	Bootes.	26 Triangulum Minus,	Little Triangle.
6 Corona Borealis.	The Northern Crown.	27 Lynx,	Lynx.
7 Hercules,	Hercules.	28 Leo Minor,	Little Lion.
8 Lyra,	The Harp.	29 Asterion et Chara,	Greyhounds.
9 Cygnis,	Swan.	30 Cerberus,	Cerberus.
10 Cassiopeia,	Cassiopeia.	31 Vulpecula et Anser,	The Fox and Goose.
11 Perseus,	Perseus.	32 Scutum Sobieski,	Sobieski's Shield.
12 Auriga,	The Waggoner.	33 Lacerta,	The Lizard.
13 Serpentarius,	Serpentarius.	34 Mons Mænalus,	A Mountain of Arcadia.
14 Serpens,	The Serpent.	35 Cor Caroli,	Charles' Heart.
15 Sagitta,	Arrow.	36 Renne,	The Rein Deer.
16 Aquila,	Eagle.	37 Le Messier,	M. Messier.
17 Antinous,	Antinous.	38 Taurus Regalis,	The Royal Bull.
18 Delphinus,	The Dolphin.	39 Friedrick's Ehre,	Frederick's Glory.
19 Equuleus,	Horse Head.	40 Tubus Herschellii	Herschel's Great Te-
20 Pegasus,	Flying Horse.	Major,	lescope.
21 Andromeda,	Andromeda.		

SOUTHERN CONSTELLATIONS.

1 Cetus,	The Whale.	28 Dorado, ou Xiphias,	The Sword Fish.
2 Orion,	Orion.	29 Toucan,	American Goose.
3 Eridanus,	River Eriadanus.	30 Hydrus,	Water Snake.
4 Lepus,	Hare.	31 Sextans,	Sextant.
5 Canis Major,	Great Dog.	32 Apparatus Sculp-	Apparatus of the
6 Canis Minor,	Little Dog.	toris,	Carver.
7 Argo Navis,	Ship Argo.	33 Fornax Chemica,	Chemical Furnace.
8 Hydra,	Hydra.	34 Horologium,	Clock.
9 Crater,	Cup.	35 Reticulus,	Reticulat. Rhomboid.
10 Corvus,	Crow.	36 Cælum Sculptori-	
11 Centaurus,	Centaur.	um,	Graving Tool.
12 Lupus,	Wolf.	37 Equuleus Pictoris,	The Painter's Basil.
13 Ara,	Altar.	38 Pyxis Nautica,	Mariner's Com-
14 Corona Australis,	Southern Crown.	pass.	
15 Piscis Australis.	Southern Fish.	39 Antlia Pneumatica,	Air-pump.
16 Columba Noachi,	Noah's Dove.	40 Octans,	Octant or Hadley's
17 Rober Carolinum,	Royal Oak.	Quadrant.	
18 Grus,	Crane.	41 Circinus,	A Pair of Compasses.
19 Phœnix,	Phœnix.	42 Norma,	The Square and Rule.
20 Indus,	Indian.	43 Telescopium,	Telescope.
21 Pavo,	Peacock.	44 Microscopium,	Microscope.
22 Apus, ou <i>Avis In-</i>	Bird of Paradise.	45 Mons Mensæ,	Table Mountain.
<i>dica.</i>		46 Solitaire,	An Indian Bird.
23 Apis, ou <i>Musca.</i>	Bee or Fly.	47 Psalterium Geor-	
24 Crux,	Cross.	gianum.	The Georgian Psaltery.
25 Chamelion,	Chamelion.	48 Tubus Herschellii	
26 Triangulum Aus-	Southern Trian-	Minor,	Herschel's less Tele-
tralis,	gle.		scope.
27 Pisces Volans, ou	Flying Fish.		
Passer.			

Three more Southern constellations have been lately added, viz. *Montgolfier's Balloon*, which is between Sagittarius, Capricorn, the Southern Fish, and the Microscope; the *Press of Gutenberg*, between the great dog and the ship; and the *Cat*, between Hydra, the ship, compass and air-pump. The two first of these constellations were formed by astronomers at Gotha, in Upper Saxony, and the last by the late M. Jerome de la Lande.

The number of Stars of the first Magnitude, in the zodiac, and in both hemispheres, do not amount to twenty.

The Pleiades, or, as they are more commonly called the Seven Stars, although only six principal stars remain, are, it is presumed, universally known. Towards the S. E. and at the distance of nearly 14° , is the star *Aldebaran*, of the first magnitude, and of a reddish colour, which, together with a few small stars, form a triangular figure. Between the N. and E. of Aldebaran, and about the angular distance of 45° , is *Pollux*, in the constellation Gemini, and at a small distance to the N. is Castor. From Pollux a little to the S. of E. at the distance of about 37° , is *Regulus*, in the constellation Leo; and from thence, at the distance of about 54° towards the East, is *Spica Virginis*. From this star, and nearly in the same direction, at the distance of about 46° , is *Antares*, of the first magnitude. From Antares to *Altair*, or α *Aquila*, in a North-easterly direction, the angular distance is nearly 61° . From Altair to *Fomalhaut*, in a South-easterly direction, the distance is about $59\frac{1}{2}^\circ$; and from thence to α *Pegasi*, or Markab, the distance is about 45° in a Northerly direction; and from α *Pegasi* to α *Arietis*, the distance is about $43\frac{3}{4}^\circ$ in a direction a little to the South of East: and Aldebaran is distant from α *Arietis* about $35\frac{1}{2}^\circ$, nearly in the same direction, but inclining a little more to the South.

Some of the other principal fixed stars, which may be employed in finding the latitude, and the apparent time at the place of observation, may be known by their relative bearing and distance from those already described. The following few directions may, probably, be acceptable to some persons.

An imaginary line from the Pleiades through Aldebaran, at the distance of about 16° from that star, in a South-easterly direction, will pass through *Bellatrix*, of the second magnitude, in the constellation Orion; and towards the East, about $7\frac{1}{2}^\circ$ from *Bellatrix*, is *Betelgeuse*, of the first magnitude, in the same constellation. To the South of these stars, and nearly on a straight line, and at equal distances, are three stars, each of the second magnitude, called the Belt or Girdle of Orion: from the belt, towards the South is the *Sword of Orion*, in which is a remarkable nebula; a line from *Betelgeuse*, between the first and second stars in the belt of Orion, will pass through *Rigel*, of the first magnitude. From *Betelgeuse*, towards the East, at the distance of about 26° , is *Procyon*, between the first and second magnitudes, in the constellation *Canis Minor*. These two stars, and *Sirius*, of the first magnitude, in *Canis Major*, towards the South, form nearly an equilateral triangle.

From Aldebaran, in a direction a little to the East of North, and at the distance of about 31° , is *Capella*, of the first magnitude; these two stars and Castor form nearly an isosceles triangle, Capella being at the vertex. A line from Rigel through Capella produced will nearly pass through *Alruccabah*, or the pole star; the distance between the two former being about 54° , and that between Capella and Alruccabah 44° . The pole star is the last in the tail of the constellation Ursa Minor, which constellation contains seven principal stars, and is similar, but differently posited with respect to Ursa Major, or the Great Bear; the two Westernmost stars of this constellation, when in the hemisphere South of the pole, are called the *Pointers*; as a line through them points out, or is nearly in a direction with the pole star.

Towards the South of Regulus, and inclining a little to the West, at the distance of about $23\frac{1}{2}^\circ$, is *Alphard*, in the constellation Hydra. From Regulus to Deneb, the distance, in a direction to the North of East, is about $23\frac{3}{4}^\circ$. From Spica Virginis to Arcturus, in a Northerly direction, the distance is 33° ; and nearly in a line between them is *Vindemiatrix*, in Virgo; to the North of this star, at the angular distance of about $27\frac{1}{2}$ degrees, is *Cor Caroli*. In a North-easterly direction from Arcturus, at the distance of $19\frac{1}{2}^\circ$ degrees, is *Alphacca*, in Corona Borealis; and from thence, nearly in the same direction at the distance of about $39\frac{3}{4}^\circ$, is *Vega*, or *a Lyra*, of the first magnitude. At the distance of 47° from Spica Virginis, towards the South, is the Northernmost of four stars, forming a cross, and therefore, called the *Crosiers*.

Nearly 14° to the North-east of Altair, is the constellation Delphinus, in which are four principal stars, in form of a rhomboid; and this line being produced from Delphinus, in the same direction will pass through *Scheat*, a star of the second magnitude, in the constellation Pegasus. About 13° to the South of Scheat, is *Markab*, a star of the second magnitude, in the same constellation; nearly $16\frac{1}{2}^\circ$ to the Eastward of Markab, is *Algenib* or γ Pegasi, of the second magnitude; and about 14° to the Eastward of Scheat, is *a Andromedæ*, or Alpheratz, a star of the third magnitude, in the head of Andromeda. These four stars form a figure which is usually called the *Square of Pegasus*.

From *a Andromedæ*, in a North-easterly direction, at the distance of nearly $14\frac{1}{2}^\circ$, is *Mirach*; and $23\frac{3}{4}^\circ$ therefrom, in the same direction, is the variable star *Algol*. In a perpendicular direction from the middle of the line joining Mirach and Algol, towards the North, and at the distance of about one-eighth of that line, is *Almaach*. About $21\frac{1}{2}^\circ$, towards the North of Mirach is *Schedir* in Cassiopeia; this constellation contains five stars of the third magnitude, and is easily known. Between the South and West of the Pleiades, at the distance of 23° , or from Aldebaran 26° , is *Menkar*, of the second magnitude. Betelguese, Rigel, and *Achernar* are nearly in the same direction, the distance between the two last being $4\frac{1}{2}$ times of that between the two first.

CHAPTER II.

ON THE DETERMINATION OF THE ERROR OF A CHRONOMETER; AND OF THE AZIMUTH OF THE REFERRING MARK FROM OBSERVATIONS MADE AT ANY TIME ON THE SUN OR A KNOWN STAR.

WHEN a chronometer forms a part of the equipment of a Surveyor, the first thing he must apply himself to is the determination of its error. This may be easily effected by an observation taken at any time to the sun or a star in the following manner.—First, to begin with the sun, which, suppose, is on the east of the meridian. With a theodolite properly adjusted, take the altitude of the sun's upper limb, noting the chronometer time of the observation. Then as the sun is ascending, allow the telescope to stand at the same elevation, and mark the chronometer time when the lower limb attains to that altitude. This will complete observations on one face of the instrument, and similar observations being repeated on the other face, there will be two observed altitudes and four chronometer times, the mean of the former is obviously the altitude of the sun's centre, divested of instrumental errors; the chronometer time corresponding thereto being the mean of the four observed times aforesaid.

On the other hand, when the sun is on the west of the meridian, and descending, the lower limb will require to be observed first and then the upper; a contrary procedure

being followed on the eastern side, because the sun was ascending. With the exception of this difference, the observations on both sides the meridian are to be conducted in exactly the same manner.

The altitude of the sun's centre being derived in the way described above, the next step is to clear it of refraction and parallax, (*vide* appendix,) an operation which will furnish what is technically called the true altitude. Deduct this altitude from 90° , the remainder will be the zenith distance of the sun's centre.

Besides the zenith distance, there will be two other quantities required in the present computation, and these are, 1st.—The sun's north polar distance, and 2nd.—The colatitude of the place of observation: the former may be taken out from the Nautical Almanac, while the latter must be derived from observations made for that purpose, or from a previous survey operation.

The three elements, viz. the sun's zenith and north polar distances, and the colatitude of the place being obtained, the computation of the chronometer error may be performed in the following manner:

1st. Collect into one sum the zenith and the north polar distance of the sun, and the co-latitude of the place, and take its half: then diminish the half sum by 1st the zenith distance, 2nd the north polar distance, and 3rd the colatitude, and call these differences in the order in which they are taken, D_1 , D_2 , D_3 .

2nd. To the log cosecant of the half sum as taken above, add the log cosecant of D_1 , and the log sines of D_2 and D_3 ; the sum divided by 2 is the log tangent of an arc, which being found and doubled, will furnish the sun's horary angle at the time of observation.

3rd. The horary angle being in space must now be converted into time, and then subtracted from the mean time of the apparent noon or added thereto, according as the observation

was made on the east or west of the meridian.* The difference or the sum, (as the case may be,) so obtained, will be the mean time of the observation.

This mean time may now be compared with the mean observed time, and the difference between the two will be the error of the chronometer.

EXAMPLE.

SPECIMEN OF THE FIELD BOOK.

*Afternoon observations taken on the sun at the Surveyor General's Office, Dehra,
15th August 1848.*

Object observed.	Face.	Vertical Vernier.						Observed Chronometer Times.					
		A.		B.		Mean.		h.	m.	s.			
☉'s Lower Limb,	L	19	45	45	19	45	15	19	45	30	10	51	29
„ Upper Limb,	„	19	45	45	19	45	15	19	45	30	10	53	59
„ Lower Limb,	R	18	54	45	18	54	15	18	54	30	10	56	20
„ Upper Limb,	„	18	54	45	18	54	15	18	54	30	10	58	49

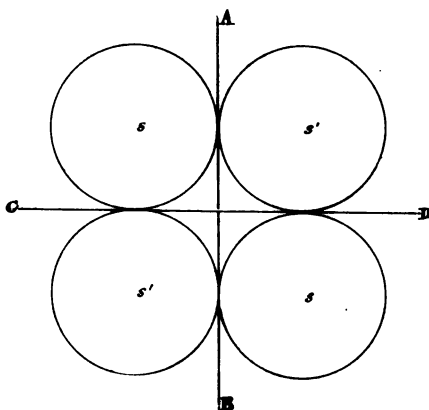
Mean observed altitude, = $\begin{matrix} \circ & / & '' \\ 19 & 20 & 0 \end{matrix}$
 h. m. s.
 Time, ... = $\begin{matrix} 10 & 55 & 9 \end{matrix}$

* For facilitating the conversion of space into time and *vice versa*, the following Tables are subjoined:

TABLE I.							TABLE II.						
<i>For converting Degrees, Minutes and Seconds into Time, at the Rate of 360 Degrees for 24 Hours.</i>							<i>For converting Time into Degrees, Minutes and Seconds, at the Rate of 24 Hours for 360 Degrees.</i>						
Deg. Min.	Hou. Min. Sec.	Deg. Min. Sec.	Hou. Min. Sec.	Sec.	Dec. of Sec.	Hou.	Deg.	Min. Sec.	Deg. Min. Sec.	Dec. of Sec.	Sec.		
1	0' 4	30	2' 0	1	.067	1	15	1	0' 15	.1	1.5		
2	0' 8	40	2' 40	2	.133	2	30	2	0' 30	.2	3.0		
3	0' 12	50	3' 20	3	.2	3	45	3	0' 45	.3	4.5		
4	0' 16	60	4' 0	4	.266	4	60	4	1' 0	.4	6.0		
5	0' 20	70	4' 40	5	.333	5	75	5	1' 15	.5	7.5		
6	0' 24	80	5' 20	6	.4	6	90	6	1' 30	.6	9.0		
7	0' 28	90	6' 0	7	.466	7	105	7	1' 45	.7	10.5		
8	0' 32	100	6' 40	8	.533	8	120	8	2' 0	.8	12.0		
9	0' 36	200	13' 20	9	.6	9	135	9	2' 15	.9	13.5		
10	0' 40	300	20' 0	10	.666	10	150	10	2' 30				
						11	165	20	5' 0				
						12	180	30	7' 30				
						16	240	40	10' 0				
20	1' 20					20	300	50	12' 30				

Analogous to this process of ascertaining the error of a chronometer, there exists a method for determining the azimuth of a Survey. To accomplish the latter object, the Surveyor will establish a referring mark at the distance of a mile from the station of observation, so that it may be visible with the solar focus of the telescope attached to his theodolite. When the referring mark has been selected with due regard to this condition, he will proceed with his observations upon the sun in the following manner.

Adjust the theodolite over the station dot, and take a reading to the referring mark, after which, turn the telescope to the sun, and placing it in one of the four angles of the wires, make those wires tangents to its sides, as shewn in the annexed figure, in which AB and CD represent the wires and S, S, S', S' the sun. Now



read off the horizontal and vertical limbs of the instrument. This done, take a similar observation of the sun in the opposite angle of the wires,* after which, bring the telescope to the referring mark, and take a second intersection thereof.

Now, compute the difference between the first azimuthal reading of the referring mark and the like reading of the sun, this will be one angle. Again, performing similar operation upon the second pair of readings, there will result another angle. The mean of these two angles will obviously be the angle between the sun's centre and the referring mark on one face. In like manner, the mean of the vertical angles

* In the Diagram the $\angle S$ is opposite to the $\angle S$ and the $\angle S'$ to S' .

observed, will be the altitude of the sun's centre on the same face.

Similar observations being made on the reversed face of the instrument, there will ultimately arise a horizontal angle and an altitude, analogous to the horizontal angle and altitude mentioned above. The mean, therefore, between the two horizontal angles so deduced, will be the angle between the referring mark and the sun's centre, cleared of facial error. For the same reason, the mean between the two altitudes will be the elevation of the sun's centre, divested of all instrumental discrepancies.

The foregoing data being obtained, the next step is the computation of the sun's azimuth. The elements involved in this deduction are 1st—The sun's true zenith distance; 2nd—Its north polar distance, and 3rd—The colatitude of the place:—the mode of deriving which, having been explained in a former part of this chapter, it will not be necessary to enter into that subject again at this place.

Combine into one sum, the sun's north polar and zenith distances and the colatitude of the place, and take its half. Diminish this half sum by 1st, the north polar distance, 2nd, the zenith distance, and 3rd the colatitude, and call these differences taken in succession D' , D'' and D''' .

To the log cosecant of half sum, add the log cosecant of D' and log sines of D'' and D''' . The resulting sum divided by 2 will be the log tangent of an arc, which being found and doubled, will be the sun's azimuth at the time of observation.

The sun's azimuth as deduced above, originates from the north, and extends towards the east or west as the observation was made on one or the other side of the meridian. Apply now this azimuth to the mean observed angle between the sun's centre and the referring mark, the resulting arc will be the required azimuth of the latter.

EXAMPLE.
SPECIMEN OF THE FIELD BOOK.
Morning Angles taken at Allahabad, Surveyor General's Office, 21st May 1845.

Objects observed.	Face.	Vernier Readings.				Angles deduced.		No. of observations at each Zero.	Vertical Verniers.		
		A.	B.	C.	Mean.	One Reading.	Mean at each Zero.		A.	B.	Mean.
Referring Mark, ⊙ (Left and Lower Limb,) ⊙ (Right and upper,)	R	275 20 45	27 15	26 15	275 26 45	o / "	o / "	2	o / "	Altitudes.	o / "
		224 48 15	49 45	48 15	224 48 25	50 38 20	50 40 10		14 27 45	25 15	14 26 30
		224 44 45	45 0	45 0	224 44 55	50 42 0			15 3 45	2 15	15 3 0
Referring Mark,		275 26 45	26 45	27 15	275 26 55				Mean,.....	14 44 45	
Referring Mark, ⊙ (Left and lower,) ⊙ (Right and upper,)	L	95 26 45	27 15	26 30	95 26 50			2	18 26 15	25 15	18 25 45
		46 27 15	27 45	27 15	46 27 25	48 50 25	49 3 10		18 56 15	55 15	18 55 45
		46 19 15	19 45	19 45	46 19 35	46 6 55			Mean,.....	18 40 45	
Referring Mark,		95 26 45	26 15	26 30	95 26 30						

Mean observed Altitude,	16	42	45		
Refraction and Parallax,	-	3	3	Mean observed angle	
True Altitude,	16	39	42	between the Sun and	} = 49 51 40
Zenith Distance,	73	20	18	Referring Mark,	

	<i>Type of Computation.</i>			
	°	'	"	
☉'s North Polar Distance,	69	40	34	
„ Zenith Distance,	73	20	18	
Colatitude of the place,	64	35	30	
Sum,	207	36	22	
Half Sum,	103	48	11	Cosec. 0.0127264
Half Sum diminished by North Polar Distance, D'	34	7	37	Cosec. 0.2510162
Ditto ditto Zenith Distance, ... D''	30	27	53	Sin. 9.7050146
Ditto ditto Colatitude, D'''	39	12	41	Sin. 9.8006430

2/19.7695992

37	29	19	Tan.	9.6847996
		2		

☉'s Azimuth,	74	58	38
Observed Angle between ☉ and referring mark,	49	51	40
Azimuth of the referring mark,	124	50	18

To make the foregoing process of observation and computation applicable to a star, take, as in the case of the sun, its altitude, and the angle which it may be inclined to with the referring mark. These observations will require to be repeated on both faces of the theodolite, and the mean results taken, to free the latter from instrumental errors. This done, clear the mean observed altitude of refraction, and deduce therefrom the star's true zenith distance. With this element, and the star's apparent north polar distance, and the given colatitude of the place, compute the star's azimuth in the same way as in the case of the sun, which azimuth, applied to the mean observed angle between the star and the referring mark, will furnish the azimuth of the latter.

To give the Surveyor an idea of the accuracy attainable by this method of determining the azimuth, the results of thirteen observations taken in the Revenue Survey of the 24-Pergunnahs are here given the mean whereof, when compared with the corresponding azimuth in the Trigonometrical Survey, exhibits an error of 27".

Results of observations taken at No. 39, Park Street, with a Troughton and Simms's 7-inch Theodolite of Col. Everest's or East India Company's Pattern.

Date.	Stars observed.	Deduced Azimuth of La Martiniere Dome.
		° ' "
17th Oct., 1848	α Cassiopeia,	168 11 44
19th " "	α Scorpio (Antares,)	11 12
23rd " "	α Bootes (Arcturus,)	12 32
25th " "	Ditto,... ..	10 8
28th " "	α Scorpio (Antares,)	10 50
2nd Nov., "	η Ursæ Major,	10 22
3rd " "	α Cassiopeia,	11 28
3rd " "	α Scorpio (Antares,)	11 44
3rd " "	α Tauri (Aldebaran,)	11 39
6th " "	α Auriga (Capella,)	11 56
8th " "	α Tauri (Aldebaran,)	11 8
8th " "	α Lyræ. (Vega,)	11 56
8th Mar., 1849	Sun,	11 32

Mean,	168 11 24
By Great Trigonometrical Survey,	168 11 51
Discrepancy,	27

These azimuths originate from the north; that of the Great Trigonometrical Survey is derived in the following manner:

Azimuth of 39, Park Street, from La Martiniere, }
 measured from south, furnished by the Officer in charge } 168 11 53·3
 of the Coast Series, }

The same augmented by π or 180° 348 11 53·3
 Correction for the convergency of the Meridian or } — 2·6
 ΔA of page 422. }

Azimuth of La Martiniere from 39, Park Street, }
 reckoned from south, 348 11 50·7

The same reckoned from North, 168·11·50·7

CHAPTER III.

ON THE DETERMINATION OF THE ERROR AND RATE OF A CHRONOMETER, UPON MEAN SOLAR AND SIDERIAL TIME, FROM MERIDIONAL OBSERVATIONS.

WHEN the direction of the meridian, or which is the same thing, the azimuth of the referring mark is known, the most convenient method of determining the error of a Chronometer upon mean solar time is by taking a meridional observation of the sun. With this view, about half an hour before noon, plant the theodolite over the station dot, and perform thereon all the necessary adjustments. This done, take a reading to the referring mark, and apply thereto the azimuth of that point; the resulting reading will obviously be the direction of the meridian. The instrument being now set to this reading and clampd, fix the telescope to the required altitude of the sun, and await its coming. When the sun has entered the telescope, bring it into the middle of the field by the motion of the vertical tangent screw alone, and then, as it advances forward, note the Chronometer times of the contact of the first and second limbs with the vertical wire of the telescope. Half the sum of the two observed times will furnish the transit of the sun's centre over the vertical wire, or the meridian of the station of observation.*

* In case both the limbs have not been observed, the method whereby the transit of the sun's centre may be derived from the transit of *one* of the limbs is as follows. In the Nautical Almanac is registered the siderial time of the sun's Semidiameter passing the meridian for every day in the year. Take this time and add it to, or subtract it from, the observed Chronometer time, according as the 1st or the 2nd limb was taken, the resulting sum or difference will be the required Chronometer time of the transit of the sun's centre.

When the sun's centre passes over a meridian, it is *apparent noon* there. The mean time of the apparent noon for a given day at any place being deducible from the Nautical Almanac, it is clear, that this time compared with the observed time of the transit of the sun's centre as deduced above, will obviously furnish the error of the Chronometer.

Again, the difference of the errors of the Chronometer on two successive days will be its rate.

EXAMPLE.

Computation of the observations made on the sun at Kaliana, G. T. Station, in Lat. 29° 30' 49" and Long. 77° 41' 52".

October 1886.	Transits of the two Limbs.	Transit of the Centre.	Mean Time of appa- rent noon.	Error.		Rate.
				Fast. h. m. s.	Gaining. s.	
5th	{ 0 2 53·9 0 5 2·0 }	0 3 57·95	23 48 26·04	0 15 31·91		
6th	{ 0 3 8·0 0 5 17·0 }	0 4 12·50	23 48 8·57	0 16 3·93	32·02	
7th	{ 0 3 22·0 0 5 31·0 }	0 4 26·50	23 47 51·50	0 16 35·00	31·07	
8th	{ 0 3 38·5 0 5 47·5 }	0 4 43·00	23 47 34·86	0 17 8·14	33·14	

Circumstances, however, will sometimes happen, which will prevent the sun from being observed. In this case, it will be necessary to resort to the transit of a star, which may be taken in the following manner:—The theodolite being duly adjusted in the plane of the meridian, the telescope may be fixed to the altitude of the star. When the star appears in the field of the telescope, it must be brought to the middle thereof, as in the case of the sun, by the motion of the vertical tangent screw only. This done, note the Chronometer time of the star's passage over the vertical wire, which will be the observed time of the transit.

It is always convenient to select a Nautical Almanac star for such observations, because its apparent right ascension being given, the computation of its transit will present little or no difficulty. For this reason we will suppose that a Nautical Almanac star has been taken. Now, the sidereal time of its transit is known, it being the star's apparent right ascension at that instant, an element which is furnished by the Nautical Almanac. Again, the same work gives the sidereal time of the mean noon for every day in the year. For any given day therefore take the sidereal time of the mean noon corrected for the longitude of the place of observation, and deduct it from the star's apparent right ascension, the difference will be the sidereal interval between the mean noon and the star's transit; which interval converted to mean solar time, will be the mean time of the transit in question.*

The mean time of the star's transit being computed, it may be compared with the observed time, and the error and rate of the Chronometer determined in the same way as in the case of an observation on the sun.

EXAMPLE.

Computation of Transit observations made on 15 Argus at Noh, G. T. Station, in Lat. 27° 50' 44" and Long. 77° 41' 13".

April 1837.	*s Apparent Right As- cension.		Sidereal Time of Mean Noon.		Mean Time of *s Transit.		Chronome- ter Time of Transit.		Error.		Rate.					
	h.	m.	s.	h.	m.	s.	h.	m.	s.	h.		m.	s.			
5th	8	0	36.66	0	53	27.66	7	5	59.02	9	32	51.73	2	26	52.71	Gaining. s.
6th	8	0	36.64	0	57	24.21	7	2	3.10	9	29	44.98	2	27	41.88	49.17
7th	8	0	36.63	1	1	20.76	6	58	7.18	9	26	37.80	2	28	30.62	48.74

Such is the way in which the error and rate of a Chronometer are computed upon the mean solar time. If the error and rate are required upon the sidereal time, however, the

* The method of converting a sidereal interval into a mean solar interval and *vice versa* is explained in the Nautical Almanac, (pages 554 to 557.)

procedure to be followed is exactly similar to that just described. For instance, suppose a transit of the sun or that of a star has been taken, the apparent right ascension of the object observed, compared with the time of observation will furnish the error of the Chronometer upon sidereal time. Again the comparison of two errors determined in this way on two consecutive days, will give the required rate.

As an example of this computation, take the same observations made on the sun at Kaliana, in October 1836.

*Deduction of the Sidereal error and rate of a Chronometer.
Kaliana Station of observation.*

October 1836.	Transit of ☉'s centre.			Apparent Right Ascension.			Error.			Rate.	
	h.	m.	s.	h.	m.	s.	Slow.			Losing.	
5th,	0	3	57.95	12	44	18.61	12	40	20.66	m.	s.
6th,	0	4	12.50	12	47	57.64	12	43	45.14	3	24.48
7th,	0	4	26.50	12	51	37.09	12	47	10.59	3	25.45
8th,	0	4	43.00	12	55	16.95	12	50	33.95	3	23.36

In the preceding computation, it is assumed, that the true azimuth of the referring mark is given, and that the theodolite has been exactly placed in the plane of the meridian. It is evident, that these are conditions, which cannot be readily fulfilled in practice. For instance, it may happen that only an approximate azimuth of the referring mark is forthcoming; or that if the true azimuth is known, the theodolite has not been truly adjusted thereto. In either case, therefore, there will be an error in the setting of the instrument, and when that error is known, the observed time of the sun's or the star's transit, will require to be reduced to the meridian, which may be done in the following manner:

To the logarithm of the azimuthal-deviation of the theodolite from the meridian taken in seconds, add the log. sine of the zenith distance of the object observed, the log. secant of

its declination, and the arithmetical complement of the logarithm of 15, the natural number answering to the sum, will be the required correction in seconds of time, positive if the transit observation were made to the East, and negative if it were taken to the West of the meridian.

When this correction is applied to the observed time of the transit, the resulting element will be the true Chronometer time of the meridional passage of the sun or the star observed.

EXAMPLE.

At G. T. Station Noh, the Theodolite was placed $3''.835$ to the west of the meridian on the 6th April 1837, and the transit of 15 Argus observed. The correction to the transit time for this Azimuthal deviation may be computed as follows :

Azimuthal deviation, .....	.....	.....	.....	"
				3.835	Log. 0.58377
Zenith Distance of 15 Argus, .....	.....		51 41 10	° ' "	Sin. $\bar{1}.89466$
South Declination of the same, .....	.....		23 50 26		Sec. 0.03873
A. C. of Log. 15, .....	.....	.....			$\bar{2}.82391$
Correction in seconds of time, .....	.....	.....		^s -0.22	Log. $\bar{1}.34107$

Now, the observed time of the transit was $9^h. 29^m. 45.20^s$, which being diminished by this correction will furnish $9^h. 29^m. 44^s.98$, as the Chronometer time of the star's passage over the meridian. Accordingly this corrected time has been made use of in computing the Chronometer errors at p. 668.

CHAPTER IV.

ON THE DETERMINATION OF THE ERROR OF A CHRONOMETER FROM OBSERVATIONS ON A HIGH AND LOW STAR.

THERE is a method of ascertaining the error and rate of a Chronometer, which only requires an approximate knowledge of the azimuth of the referring mark. The method consists in taking the transits of a high and low star* with a theodolite placed as nearly as possible in the plane of the meridian. The only precaution, to be attended to in taking these observations, is that when the instrument is once set to the meridian, it must not be moved in azimuth, until both the required transits are taken.

The transits of a high and low star, taken as directed above, furnish two results at once; namely, 1st, the deviation of the instrument from the plane of the meridian, and 2nd, the

* "In general, the two stars suitable for this purpose, ought to have opposite declinations, one North and the other South, having nearly the same right ascension, and being removed from each other by not less than forty degrees."
—*Pearson's Astronomy*, Vol. 2nd, p. 331.

error and rate of the Chronometer. The former of these articles having been treated of in sufficient detail in a former part of the work (pages 175, 176) it need not again occupy our attention at this place; the latter, however, is the especial subject of this chapter, and to that accordingly we will direct the attention of the reader.

The problem of determining times from the transits of a high and low star, may be divided into two cases: 1st, when the high star is observed above the pole, and 2nd, when it is taken below the pole. Each of these cases may again be subdivided into two others, with reference to the North or South position of the low star with respect to the equator.

The separate consideration of the several cases is necessary to the due understanding of the formulæ, which will be given presently.

We will suppose that the stars selected for observation are those of the Nautical Almanac, and use the following symbols to designate the computed and observed elements, appertaining to them.

<i>Explanation of the Symbols.</i>		
	High Star.	Low Star.
Apparent Declination as given in the Nautical Almanac for the date nearest the time of observation,	d	d'
Apparent Right Ascension at the time of Transit,	R	R'
Observed time of Transit,	t	t'
Correction for time of Transit,	δp	$\delta p'$

λ = Latitude of the place of observation.

TO COMPUTE t^s .

Take the difference between the right ascensions of the two stars, and convert it to Chronometer time; compute likewise the difference between the observed times of their transits; subtract one difference from the other, and call the resulting quantity t^s , which will require to be taken in seconds and in decimals thereof.

The fundamental quantity t^s being computed, the corrections δp and $\delta p'$ may be deduced by the following formulæ:

Case I.—When the high star is observed above the pole, the low star having north declination.

$$\delta p = \frac{\cos d' \sin (d-\lambda)}{\cos \lambda \sin (d-d')} \cdot t^s$$

$$\delta p' = \frac{\cos d \sin (\lambda-d')}{\cos \lambda \sin (d-d')} \cdot t^s$$

The low star having south declination.

$$\delta p = \frac{\cos d' \sin (d-\lambda)}{\cos \lambda \sin (d+d')} \cdot t^s$$

$$\delta p' = \frac{\cos d \sin (\lambda+d')}{\cos \lambda \sin (d+d')} \cdot t^s$$

Table exhibiting the signs of corrections δp & $\delta p'$.

Conditions.	Signs of correction.	
	δp	$\delta p'$
When the low star transits after the high star, or $t'-t > \mathcal{R}'-\mathcal{R} \dots \dots \dots$	$t' > t$ +	-
$t'-t < \mathcal{R}'-\mathcal{R} \dots \dots \dots$	-	+
When the high star transits after the low star, or $t-t' > \mathcal{R}-\mathcal{R}' \dots \dots \dots$	$t > t'$ -	+
$t-t' < \mathcal{R}-\mathcal{R}' \dots \dots \dots$	+	-

Case II.—When the high star is observed below the pole, the low star having north declination.

$$\delta p = \frac{\cos d' \sin (\lambda + d)}{\cos \lambda \sin (d + d')} \cdot t^s$$

$$\delta p' = \frac{\cos d \sin (\lambda - d')}{\cos \lambda \sin (d + d')} \cdot t^s$$

The low star having south declination.

$$\delta p = \frac{\cos d' \sin (\lambda + d)}{\cos \lambda \sin (d - d')} \cdot t^s$$

$$\delta p' = \frac{\cos d \sin (\lambda + d')}{\cos \lambda \sin (d - d')} \cdot t^s$$

<i>Table exhibiting the signs of corrections δp & $\delta p'$.</i>		
Conditions.	Signs of correction.	
	δp	$\delta p'$
When the low star transits after the high star, or	$t' > t$.	
$t' - t > \mathcal{R}' - \mathcal{R} \dots \dots \dots$	+	+
$t' - t < \mathcal{R}' - \mathcal{R} \dots \dots \dots$	-	-
When the high star transits after the low star, or	$t > t'$.	
$t - t' > \mathcal{R} - \mathcal{R}' \dots \dots \dots$	-	-
$t - t' < \mathcal{R} - \mathcal{R}' \dots \dots \dots$	+	+

Of the four heads under which the formulæ of computation are given, the intelligent Surveyor will take that which will suit his case, and proceed with his arithmetical deductions accordingly.

When δp and $\delta p'$ are computed, and proper signs affixed thereto, they may be applied, the former to t , and the latter to t' ; the resulting elements will be the times of the meridional passages of the stars observed; whereby the error and the rate of the Chronometer may be easily determined.

EXAMPLE.

Computation of the transit observations made at Sora, Karara Series Station, in October 1845.
Latitude of Sora = $26^{\circ} 17' 17''$, Longitude $81^{\circ} 14' 50''$ or $5.416h$.

Date.	Apparent Right Ascensions.		$R - R'$	$R - R'$ in Chronometer time.	Observed Times of Transits.		$(t - t')$	t''	$\delta p'$	δp
	α° Capricorni.	λ Urse Minors.			α° Capricorni.	λ Urse Minors.				
9	h. m. s. 20 9 30.65	h. m. s. 20 16 59.01	s. 448.36	s. 447.34	h. m. s. 1 56 14.5	h. m. s. 2 2 39.0	s. 384.5	s. 62.84	s. -0.91	s. + 61.93
10	20 9 30.63	20 16 57.86	447.23	446.21	1 52 58.0	2 59 24.5	386.5	59.71	-0.86	+ 58.86
11	20 9 30.61	20 16 56.71	446.10	445.08	1 49 39.2	1 56 6.0	386.8	58.28	-0.84	+ 57.45
12	20 9 30.60	20 16 55.55	444.95	443.94	1 46 21.2	1 53 13.0	411.8	32.14	-0.46	+ 31.68
13	20 9 30.58	20 16 54.38	443.80	442.79	1 43 6.3	1 49 43.0	396.7	46.09	-0.66	+ 45.43

Table exhibiting the results of the transit observations taken at Sora, Karara Series Station, in October 1845.

<i>a</i> ² Capricorni.						
Date.	Chronometer Times of Transits.	$\delta P'$	Chronometer Times Corrected.	Apparent Right Ascensions.	Chronometer.	
					Error.	Rate.
	h. m. s.	s.	h. m. s.	h. m. s.	h. m. s.	m. s.
9	1 56 14.5	-0.91	1 56 13.59	20 9 30.65	18 13 17.06	
10	1 52 58.0	-0.86	1 52 57.14	20 9 30.63	18 16 33.49	3 16.43
11	1 49 39.2	-0.84	1 49 38.36	20 9 30.61	18 19 52.25	3 18.76
12	1 46 21.2	-0.46	1 46 20.74	20 9 30.60	18 23 9.86	3 17.61
13	1 43 6.3	-0.66	1 43 5.64	20 9 30.58	18 26 24.94	3 15.08

λ Ursæ Minoris.						
Date.	Chronometer Times of Transits.	δP	Chronometer Times Corrected.	Apparent Right Ascensions.	Chronometer.	
					Error.	Rate.
	h. m. s.	s.	h. m. s.	h. m. s.	h. m. s.	m. s.
9	2 2 39.0	+ 61.93	2 3 40.93	20 16 59.01	18 13 18.08	
10	1 59 24.5	+ 58.86	2 0 23.36	20 16 57.86	18 16 34.50	3 16.42
11	1 56 6.0	+ 57.45	1 57 3.45	20 16 56.71	18 19 53.26	3 18.76
12	1 53 13.0	+ 31.68	1 53 44.68	20 16 55.55	18 23 10.87	3 17.61
13	1 49 43.0	+ 45.43	1 50 28.43	20 16 54.38	18 26 25.95	3 15.08

It is necessary to remark that the Chronometer errors and rates deduced in this example, are upon sidereal time, and if they are required in terms of the mean time, the necessary reduction may be easily made by a reference to the following Chapter.

CHAPTER V.

ON THE CONVERSION OF A GIVEN CHRONOMETER TIME TO THE CORRESPONDING MEAN SOLAR AND SIDERIAL TIME, AND VICE VERSA.

It will have already appeared to the reader of the foregoing pages, that whether the error of a Chronometer is determined from a meridional or an extra meridional observation, the general principle of deduction is the same in both cases. For instance in either case, the *mean solar time* of the observation is first computed. It is then compared with the *observed time*, and the difference between the two is taken as the error of the Chronometer.

It is convenient to have this process expressed in Algebraical symbols. For this purpose, let s designate the *mean solar time* of an observation, and c the *Chronometer time* corresponding thereto, then $s - c = e$ is the Chronometer error at the instant of that observation. Again, calling s' and c' analogous elements to s and c for a subsequent observation, there will arise $s' - c' = e'$ the Chronometer error at the time of the second observation.

Suppose t to be the Chronometer time lying between c and c' , which is required to be converted to mean solar time. It is clear that if the Chronometer error ϵ at the time t , were known, then $t \pm \epsilon$ would be the *mean solar time* sought, the upper sign being used when $s > c$, and the lower sign when $s < c$.

The term ϵ may be computed in the following manner: subtract c from c' and t , the resulting terms $(c'-c)$ and $(t-c)$ will represent Chronometer intervals, the former between c' and c , and the latter between t and c . Again $e' \propto e$ stands for the rate, or the increment or decrement (as the case may be) of the Chronometer error engendered during the interval $(c'-c)$. Now assuming rates to be proportional to the intervals, during which they are produced, we shall have

$$(c-c') : (e' \propto e) :: (t-c) : \text{---}$$

The fourth term when brought out, will represent the rate produced during the interval $(t-c)$. When the first error e has been corrected by this rate, the resulting term will obviously be ϵ or the error at the time t .

EXAMPLE.

Suppose at Kaliana, 5th October 1836, the given Chronometer time is $5^h 56^m 27^s$ it is required to compute the mean solar time corresponding thereto.

On reference to page 667 of this work, it will be seen that the numerical values of $s, c, e \dots$ for the 5th and 6th October are as follows:

<i>5th October.</i>				<i>6th October.</i>			
	h.	m.	s.		h.	m.	s.
s	= 23	48	26.04	s'	= 23	48	8.57
c	= 0	3	57.95	c'	= 0	4	12.50
e	= 0	15	31.91	e'	= 0	16	3.93
$c'-c$	= 24	0	14.55				
$t-c$	= 5	54	29.05				
$e' \propto e$			= 32.02				

Rate for $(t-c)$ Computed.

$(c'-c)$	in seconds	86414.55	Log.	4.9365869
				<hr/>
			A. C.	5.0634131
$e' \propto e$	ditto,	32.02	Log.	1.5054213
$(t-c)$	ditto,	21269.05	Log.	4.3277481
				<hr/>
Required rate,	....	7.88	Log.	0.8965825

This rate is positive, because the error is increasing, e being $< e'$

Hence $\epsilon = \begin{matrix} \text{h.} & \text{m.} & \text{s.} & & \text{s.} & & \text{h.} & \text{m.} & \text{s.} \\ = & 0 & 15 & 31.91 & + & 7.88 & = & 0 & 15 & 39.79 \end{matrix}$
and $(t-\epsilon) = 5 \ 42 \ 47.21$ Mean solar time, corresponding to t .

After having reduced a given Chronometer time to the corresponding mean solar time, the latter may now be converted to sidereal time, in the following manner.

Refer to the Nautical Almanac and take out the mean time of the transit of the first point of Aries immediately prior to the given mean time. Now deduct this transit time from the given mean time, the difference converted to sidereal interval will be the sidereal time sought.

EXAMPLE.

Take the mean solar time given above for Kalia, 5th October 1836.

	h.	m.	s.
Given mean solar time,	5	42	47.21
Mean Time of transit of first point of Aries,	11	6	12.65
Mean solar interval,	18	36	34.56
Corresponding sidereal interval or the sidereal time sought,	18	39	37.99

The transit of the first point of Aries used in this computation belongs to the 4th October, because it is that which immediately precedes the given *mean time*, the same point transiting on the 5th which is after the *given time*.

In the foregoing part of this chapter, the Chronometer errors e and e' are taken with reference to the *mean solar time*. This however is a circumstance which cannot always be expected to obtain in practice. For instance, it may sometimes happen that the terms e and e' are known with reference to the *sidereal time* only. When this is the case, the given Chronometer time t cannot at once be reduced to the corresponding *mean solar time*. It must, in the first place, be converted to *sidereal*, and then if required, to *mean solar time*.

With respect to the former of these reductions, the process to be followed is exactly similar to that used for the conversion of any given Chronometer, to the corresponding *mean solar time*, the given terms s, e, s', e' in this instance, being taken in terms of the sidereal, in lieu of the mean solar time. When the sidereal time is computed, the corresponding mean solar time may be determined in the following manner:

Take out from the Nautical Almanac the sidereal time of the mean noon, immediately preceding the given sidereal time. Subtract the mean noon time so found from the given sidereal time, the difference converted to mean solar interval, will be the mean time sought.

EXAMPLE.

In illustration of this computation take the same example as that given before, viz., the Chronometer time $t = 5^h 58^m 27^s$ as observed at Kaliana, 5th October 1836, and it is required to reduce it successively to the corresponding sidereal and mean solar times.

The sidereal values of s , e , s' , and e' as given at page 669, are as follows :

5th October 1836.			6th October.				
m.	h.	s.	m.	h.	s.		
$s =$	12	44	18·61	$s' =$	12	47	57·64
$c =$	0	3	57·95	$e' =$	0	4	12·50
$e =$	12	40	20·66	$e' =$	12	43	45·14
							sidereal errors.
			h. m. s.				
			$c' - c =$	24	0	14·55	
			$t - c =$	5	54	29·05	
			$e' - e =$	3	24·48	sidereal rate.	

Sidereal rate for $t - c$ Computed.

$c' - c$ in seconds	86414·55	Log.	4·9365869
		A. C.	5·0634181
$e' - e$ ditto,	204·48	Log.	2·3106508
$t - c$ ditto,	21269·05	Log.	4·3277481
Required sidereal rate,	50·33		1·7018120

Hence $\epsilon = 12^h 40^m 20·66^s + 50·33^s = 12^h 41^m 10·99^s$
 And $(t + \epsilon) = 18^h 39^m 37·99^s$ sidereal time corresponding to t .
 In this case, ϵ is made + because $s \searrow c$.

To compute the mean solar time answering to Chronometer time t .

Computed sidereal time for t ,	h. m. s.	18	39	37·99
Sidereal time of mean noon for 5th October,		12	55	54·46
Difference,		5	43	43·53
Difference reduced to mean solar interval or the mean } time required, }		5	42	47·21

Before the chapter is concluded, it is necessary to shew the method of working the following problem :

Given a mean solar or a sidereal time σ , to compute the Chronometer time t corresponding thereto. Retaining the characters we have already used, we will represent by s and s' the mean solar or the sidereal times (as the case may be) of the two *time* observations, one taken before and the other after σ . c and c' being the Chronometer times corresponding to s and s' and e and e' the Chronometer errors derived therefrom.

Now deduct s first from s' , and then from σ ; the resulting differences $(s'-s)$ and $(\sigma-s)$ stand for the mean solar or sidereal intervals, the former between s' and s and the latter between σ and s . Again the rate produced during the interval $(s'-s)$ is $e' \oslash e$, whence the rate for $(\sigma-s)$ will be the fourth term to the following proportion.

$$(s'-s) : (e' \oslash e) :: (\sigma-s) : \text{---}$$

The fourth term being computed and applied to e , will furnish the Chronometer error ϵ at the given time σ . Correcting σ by the error so found, there will result the required Chronometer time t .

In the foregoing explanation the given terms s and s' and that required to be reduced σ , are supposed to be of the same denomination. But in practice this may not always be the case. For instance s and s' may be *mean solar* and σ a *sidereal time* or *vice versa*; that is s and s' being sidereal and σ a mean solar time. In the former case, σ must be converted to *mean solar* and in the latter to *sidereal time*, after which the necessary reduction may be made as directed above.

CHAPTER VI.

ON THE METHOD OF DETERMINING THE AZIMUTH OF THE REFERRING MARK FROM AN OBSERVATION TAKEN TO A CIRCUMPOLAR STAR, AT THE TIME OF ITS MAXIMUM ELONGATION.

WHEN the north polar distance of a star falls short of the latitude of a place, it becomes what is called a circumpolar star at that place, that is to say, a star which never sets, but is continually above the horizon, describing in the course of a sidereal day, a small circle round the pole, of greater or less magnitude, according to the length of the star's north polar distance.

In the diurnal circular path, above adverted to, of a circumpolar star, there are two points, one of which is furthest east, and the other furthest west from the north pole. When the star arrives at the one or the other of those points, it is said to be at its maximum elongation, that to the east, being called the *eastern*, while that on the west, is styled the *western elongation*.

When a circumpolar star arrives at its maximum elongation, it becomes on account of its slow azimuthal motion a very convenient object for observation for the purpose of determining the azimuth of the referring mark. For this purpose, the elements which are required to be known with reference to it, are three in number, and they are as follows:—1st, the time of the elongation, 2nd, the star's azimuth, and 3rd, its

altitude. The formulæ whereby these elements may be computed are given below:—

$$1st. \text{ For Horary Angle, } \dots \cos P = \tan \alpha \tan \lambda$$

$$2nd. \text{ For Azimuth, } \dots \dots \sin A = \sin \alpha \sec \lambda$$

$$3rd. \text{ For Altitude, } \dots \dots \sin Alt = \sec \alpha \sin \lambda$$

In these expressions, α stands for the star's north polar distance, and λ for the latitude of the place; P , A , and $alt.$ being the required elements, the first, the star's Horary Angle, the second, its azimuth, and the third, its altitude.

TYPE OF COMPUTATION.

α Ursæ Minoris observed at Kaliana, G. T. Station, on the afternoon of the 5th October 1836.

	° ' "	° ' "	° ' "
*'s North Polar Distance α =	1 33 43.74		
Latitude of Kaliana ... λ =	29 30 49.		
<i>Tan</i> α ... 8.4357077	<i>Sin</i> α ... 8.4355463	<i>Sec</i> α ... 0.0001615	
<i>Tan</i> λ ... 9.7528827	<i>Sec</i> λ ... 0.0603616	<i>Sin</i> λ ... 9.6925211	
<i>Cos</i> P ... <u>8.1885904</u>	<i>Sin</i> A ... <u>8.4959079</u>	<i>Sin alt</i> ... <u>9.6926826</u>	
° ' "	° ' "	° ' "	
$P = 89 \ 6 \ 55.56$	$A = 1 \ 47 \ 42.55$	$Alt. = 29 \ 31 \ 32.43$	

When the Horary Angle is brought out in the way directed above, it will be in space, and will require to be converted into time. When this reduction is made, the resulting element added to or subtracted from, the star's apparent right ascension, will furnish the sidereal time, in the former case of the western, and in the latter of the eastern elongation, which sidereal time may be converted to corresponding mean solar or chronometer time, as may be required, agreeably to the precepts given in Chapter V.

EXAMPLE.

Thus the Horary Angle computed above, converted to time, will be $5^h 56^m 27.70$, and the star's apparent right ascension is $1^h 1^m 42.72'$; hence the sidereal times of the eastern and western elongations are $19^h 5^m 15.02$ and $6^h 58^m 10.42$, the same in mean solar time being $6^h 8^m 20'$, $17^h 59^m 19'$.

After the preliminary computation has been gone through, the next step is to take the required observation upon the circumpolar star, which may be done in the following manner :—About a quarter of an hour before the maximum elongation, plant the theodolite over the station dot, and perform thereon all the necessary adjustments. This done, take a reading to the referring mark. To this reading apply the angle* between the referring mark and the star, the resulting reading is obviously the azimuthal direction of the latter. When the instrument is set in this direction, and the telescope raised to the computed altitude, intersect as accurately as possible the star, which will be found near the cross wires. The maximum elongation not having as yet occurred, the star will be receding from the meridian, continue therefore intersecting it, until it reaches the utmost limit in the direction of its motion. When an intersection has been obtained at that limit, read off the instrument, after which take a second observation to the referring mark.†

The mean between the two readings of the referring mark may be treated as one reading, and the difference between it and the reading of the star will be the angle between the two objects observed, which angle being applied to the star's computed azimuth, will furnish the azimuth of the referring mark.

The observation above mentioned appertains to one of two faces of the zero, to which the instrument was set. On the succeeding night, a similar observation will require to be made

* It will be sufficient if this angle is known to within 2' or 3', and a result within this limit may always be obtained in the following manner :—Determine an approximate azimuth of the referring mark by an observation upon the sun as explained at pp. 661, 662, add this azimuth to the star's azimuth or subtract one from the other, according as the referring mark and the star lay on different or on the same side of the meridian : the sum or difference so derived, will be the angle sought.

† This process will not be necessary when a good chronometer is at hand, because the time of the maximum Elongation being then accurately indicated ; an observation on the star at that instant, will furnish the angle sought.

on the opposite face of the same zero. In this way all the zeros being disposed of, the mean of all the observations will be the true azimuth of the referring mark.

Whenever practicable, the azimuth of the referring mark ought to be derived from two elongations of a star. When this can be done, the deduced azimuth will not be affected by the errors which may exist in the given latitude and north polar distance. On the other hand, an azimuth obtained from a single elongation will be impregnated with the full effect of those errors.*

It ought to be mentioned at this place that prior to the year 1832, all the azimuths in the Great Trigonometrical Survey of India were determined by observations taken to stars at their maximum elongations. The method is susceptible of great accuracy, as will appear from an inspection of the following Table extracted from Col. Everest's Indian Arc, published in 1830, and containing a record of the observations made on α Ursæ Minoris at the time of its western elongation, together with the azimuths of the referring mark deduced therefrom.

* As the apparent North polar distance of a star is continually changing its value from one day to another, it is clear that the horary angle and the azimuth, which are derived from it, will require a fresh and independent computation, for every elongation observed. This is a tedious process which may be easily avoided by using the following differential formulæ.

$$\begin{aligned} \delta P \text{ (in seconds of time,)} &= - \frac{\tan \text{ alt. } \sec \alpha}{15} \cdot \delta \alpha \\ \delta A \text{ (in seconds of space,)} &= \frac{\sec \lambda \cdot \operatorname{cosec} P}{\sec \lambda} \delta \alpha \end{aligned}$$

wherein $\delta \alpha$ stands for the variation (supposed to be given in seconds) which has taken place in the star's North polar distance since the 1st day's observation, δP , δA being the corresponding alterations, the former in the horary angle and the latter in the azimuth: compute therefore the azimuth A , the horary angle P , and the altitude of the star for the first elongation observed, and then making $\delta \alpha$ the difference between the North polar distance on the 1st and any subsequent day of observation; deduce δP and δA , and apply them respectively to P and A , the resulting terms will obviously be those which appertain to the star's polar distance $\alpha \pm \delta \alpha$.

As to the signs of δP and δA , it will be remembered that the former will be negative and the latter positive, when the star's North polar distance is increasing; and that they will be of the contrary affections when the North polar distance is diminishing.

OBSERVED AZIMUTHS.
 KALAMFUT, NOVEMBER 1824.
α Ursæ Minoris—Western Elongation.

Time.	Observed Objects.	3 Feet Theodolite.						Mean.	Angles.	%s Computed Azimuths.	Deduced Azimuths of Referring Mark East.		
		Micrometer A.			Micrometer B.								
		°	'	"	°	'	"	°	'	"	"		
1824. 13th November, h. m. s. 15 44 10.5	Star, Referring Mark,	150	1	50	150	2	2	150	1	56	1 46 43.5	1 46 39.63	13.87
14th November, 15 30 51	Star, Referring Mark,	136	4	46.5	136	5	6	136	4	56.25	1 46 55.75	29.26	26.49
15th November, 15 30 46	Star, Referring Mark,	118	16	29	118	16	53	118	16	43.5	1 46 53.5	28.90	24.90
16th November, 15 32 41	Star, Referring Mark,	96	23	12	96	23	89	96	23	25.5	1 46 54.75	28.56	26.19
17th November, 15 30 7.45	Star, Referring Mark,	78	20	55.5	78	21	20	78	21	7.75	1 46 53.25	28.24	25.01
18th November, 15 24 44	Star, Referring Mark,	56	23	26	56	23	52	56	23	39	1 46 43.0	27.91	15.09
19th November, 15 21 20	Star, Referring Mark,	38	19	55.5	38	19	15	38	19	5.25	1 46 40.25	27.58	13.87
20th November, 15 15 33	Star, Referring Mark,	18	13	55	18	14	16	18	14	5.5	1 46 46.0	27.25	18.75
21st November, 15 9 17	Star, Referring Mark,	176	10	57	176	11	17	176	11	7	1 46 45.75	26.92	18.83
		177	57	40.5	177	57	5	177	57	52.75			

CHAPTER VII.

ON THE METHOD OF DETERMINING THE AZIMUTH OF THE REFERRING MARK, FROM OBSERVATIONS TAKEN TO A CIRCUMPOLAR STAR NEAR THE TIME OF ITS MAXIMUM ELONGATION, AS PRACTISED IN THE GREAT TRIGONOMETRICAL SURVEY OF INDIA, ALSO ON THE MODE OF FINDING THE VARIATION OF THE NEEDLE.

It is clear that when a circumpolar star is taken in the way described in the preceding chapter, only one observation can be made at one elongation. This is a great limitation of the powers of the observer. To extend this power, the procedure, introduced by Col. Everest into the Trigonometrical Survey, consists in taking a circumpolar star, a certain number of times *before* and *after* its greatest elongation; and in subsequently reducing these observations to the star's maximum position, and then working out the azimuth as before explained. In addition to a theodolite, a good chronometer is absolutely necessary to carry this process into effect.

Col. Everest's method of taking a circumpolar star may be described as follows:—About an hour before the maximum elongation of a star selected for observation, the observer will adjust the theodolite over the station dot, and set it to a given zero. When this is effected, take a reading to the Referring Mark; and then having fixed the telescope to the star's computed altitude, move it azimuthally by the hand, until the star appears in the field of vision. Now fasten the horizontal clamp, and by the usual appendages of slow motion, place the star in the upper angle of the wires, if it is descending, or in the lower angle, if it is ascending. This

done, call out to the assistant to count the seconds' beats of the chronometer, at the same time watch the star's approach to the intersection of the wires. As soon as the star comes over the said intersection,* mark the time, and then read off the azimuthal limb. Now loosen the horizontal clamp, and after moving the telescope by the hand a few degrees in advance, bring it back to the star, and then take another intersection thereon in the same way as before; after which lower the telescope and make an observation on the Referring Mark. This will complete a set of observations on one face of the theodolite. As to the manner of treating these observations, it will perhaps be useful to note that one angle will be derived from the first pair of the readings of the Referring Mark and the star, while another angle will be obtained from the second pair of the readings taken on the same objects.

When observations on one face of the instrument have been made as described above, the observer will now reverse the face of the theodolite, and take a second set of intersections similar to the first. In this manner, when he has done with one face, he will revert to the other, until, as may be required, four or six changes of face are regularly gone through. This will complete observations on one zero, at a given elongation of a circumpolar star.

The system of changing the zero of a theodolite as explained at pp. 403-405 will require to be practised in circumpolar star observations in the same rigorous manner as in observations on terrestrial signals; for the graduation errors which that procedure is supposed to correct, have a tendency to vitiate equally the two classes of observations, and in both cases, therefore, they must be eliminated by similar arrangements and artifices. When a circumpolar star is being observed, it is convenient to adjust the changes of zero by the Referring Mark.

* To do this well, will require a little practice. After two or three trials, the observer will know the direction of the star's motion, and when he has acquired this, he will intuitively place the cross-wires, so that the star may at once come upon it.

The subjoined is a specimen of the Angle Book for registering circumpolar star observations.

SPECIMEN OF THE ANGLE BOOK.
*a Urse Minoris at Eastern Elongation observed at Kaliana, G. T. Station, on
 the afternoon of the 5th October 1836, with a three feet Theodolite.*

Objects.	Face.	Micrometer Readings.							Angles. ° ' "	Chrono- meter Times.
		A.	B.	C.	D.	E.	Mean.			
Referring Mark, ...	E	189 1 57	119	37.9	22.2	15.0	189 1 18.54	1 47 3.96	h. m. s.	
α Urse Minoris, ...	E	190 48 9.2	167	41.4	25.2	20.0	190 48 22.50	1 47 8.50	6 0 25	
Referring Mark, ...	E	190 48 14.3	23.5	46.9	31.1	24.7	190 48 28.10			
Referring Mark, ...	L	189 1 5.5	12.4	38.8	24.9	16.4	189 1 18.60			
Referring Mark, ...	L	9 1 9.0	16.8	43.9	24.2	14.3	9 1 21.64			
α Urse Minoris, ...	L	10 48 35.2	43.2	69.1	51.2	41.3	10 48 48.00	1 47 26.36	6 7 32	
Referring Mark, ...	L	10 48 38.0	45.7	71.3	55.3	45.3	10 48 51.12	1 47 29.36	6 9 36	
Referring Mark, ...	E	9 1 9.3	17.5	52.0	25.0	15.0	9 1 21.76			
Referring Mark, ...	E	189 1 5.8	14.5	39.5	23.2	15.5	189 1 18.70	1 47 39.82	6 16 23	
α Urse Minoris, ...	E	190 48 46.7	55.0	78.9	61.0	56.0	190 48 59.52	1 47 41.36	6 19 58	
Referring Mark, ...	E	190 48 46.3	55.0	79.3	63.9	54.1	190 48 59.52			
Referring Mark, ...	L	189 1 4.9	12.1	38.9	22.4	14.5	189 1 18.16			
Referring Mark, ...	L	9 1 6.5	16.1	41.5	21.6	11.7	9 1 19.52			
α Urse Minoris, ...	L	10 48 53.2	62.1	87.7	70.0	60.9	10 48 67.78	1 47 47.26	6 26 22	
Referring Mark, ...	L	10 48 52.5	60.2	85.4	67.9	60.2	10 48 5.24	1 47 45.36	6 28 59	
α Urse Minoris, ...	L	9 1 6.8	15.0	41.1	22.9	13.6	9 1 19.88			
Referring Mark, ...	E	189 1 3.5	9.0	35.9	21.2	13.5	189 1 16.62	1 47 36.08	6 37 0	
α Urse Minoris, ...	E	190 48 39.9	47.5	73.0	56.0	49.1	190 48 52.70	1 47 27.18	6 38 19	
Referring Mark, ...	E	190 48 32.7	40.2	64.0	48.2	41.0	190 48 45.72			
Referring Mark, ...	L	189 1 4.5	11.1	38.0	22.8	13.7	189 1 18.04			
Referring Mark, ...	L	9 1 7.5	17.8	43.1	24.0	12.5	9 1 20.98	1 47 11.30	6 47 18	
α Urse Minoris, ...	L	10 48 19.5	28.0	53.9	33.7	26.3	10 48 32.28	1 47 2.80	6 46 15	
Referring Mark, ...	L	10 48 12.0	21.3	46.1	26.9	18.8	10 48 25.02			
Referring Mark, ...	L	9 1 9.9	17.2	44.4	26.0	13.6	9 1 22.22			

To obtain the best angles which a theodolite is capable of furnishing, the motion of the telescope, whether proceeding from the Referring Mark to the star, or *vice versa*, should be continuous and in one direction, never allowing the telescope or rather the cross-wires contained therein, to pass the object to be intersected, and then be brought back to it. This mode of taking an observation, although difficult at first, is rendered very easy after a little practice.

With a view of computing these observations, the first thing to be done is the conversion of the observed chronometer times to corresponding sidereal times, the mode of executing which has been explained in Chapter V. When this reduction is made, take the difference between the sidereal time of each observation and that of the maximum elongation, and convert it into space. Let δP stand for the elements so derived.

Now δP being the interval elapsed between each observation and the star's maximum position, the term, which is now required to be known, is the azimuthal variation δA corresponding thereto. This term may be computed by the following formulæ:

1st. *When the star is observed below the maximum position.*

$$\tan \delta A = \frac{2 \sin^2 \frac{1}{2} \delta P}{\sin P \cot \alpha \cos \lambda \{ 1 + \tan^2 \alpha \cos \delta P + \sec^2 \alpha \cot P \sin \delta P \}}$$

2nd. *When the star is taken above the maximum position.*

$$\tan \delta A = \frac{2 \sin^2 \frac{1}{2} \delta P}{\sin P \cot \alpha \cos \lambda \{ 1 + \tan^2 \alpha \cos \delta P - \sec^2 \alpha \cot P \sin \delta P \}}$$

in which as stated elsewhere λ represents the latitude of the place, α standing for the star's North polar distance, and P for the horary angle at its maximum position East or West.*

* As the star *ascends* on the East side of the meridian, the observations made *before* the Eastern elongation are reduced by the first formula, and those taken after, are computed by the second. In the Western elongation, a contrary procedure is followed, because the star is *descending*; the second formula being used in deducing the *prior*, and the first in computing the *subsequent* observations.

These formulæ have been investigated by Babu Radhanath Sickdhar, chief computer to the Great Trigonometrical Survey, and are applicable to all circumpolar stars, irrespective of the lengths of their North polar distances, and they are now used in all the rigorous computations of the Great Trigonometrical Survey.

The terms δA being computed and applied to the observed angles, we obtain the angles as if taken at the star's maximum elongation. To these angles, the star's computed azimuth being applied, the resulting elements will be the required azimuths of the Referring Mark.

It will be seen that this deductive process, although suited to the requirements of a Trigonometrical Survey, will prove much too operose, if applied to an operation of a lower order. To meet the wants of the latter, therefore, we will describe an approximate method of computation, derivable from the above formulæ, and which when applied to α Ursæ Minoris, will not produce an error of a second in the result.

This approximate process of computation is as follows :

1st. Compute the following constant logarithm.

$$0.29303 + \log \sec \lambda + \log \tan \alpha + \log. \operatorname{cosec} P.$$

2nd. Compute as accurately as the means will allow to the nearest second, the chronometer time of the star's maximum elongation observed.

3rd. Compute the chronometer interval elapsed between each observation and the maximum elongation, and convert it to minutes and decimals thereof.

4th. Take the logarithm of the interval converted to minutes as directed above, double it, and add thereto the constant log, deduced according to precept 1st. The natural number answering to the sum is δA in seconds.

5th. In making this computation, the logarithms used need not be carried beyond 5 decimals.

To carry this method into effect, we would recommend to the Surveyor to derive his azimuths from observations made to α

Ursæ Minoris alone, which is a star generally known, and of easy recognition. The chronometer time of the star's Eastern or Western elongation (as the case may be) being deduced, two pairs of angles may be taken before, and two pairs after that event, as described at pp. 687, 688. The corrections to these angles being computed by the approximate process, and applied, we shall have the angles at the star's maximum position. When these angles are combined with the star's computed azimuth, there will result the required azimuths of the Referring Mark.

Type of Computation by the Approximate Process.

Take the observations made at Kaliana, on the 5th October 1836, given at p. 689.

<i>Constant Logarithm Computed.</i>					
Constant Log. as per Rule,	°	'	"		0.29303
Latitude of Kaliana,	$\lambda =$	29	30	49	sec 0.06036
*'s North Polar Distance,	$a =$	1	33	44	tan 8.43573
Horary Angle,	$P =$	89	6	56	} cosec 0.00005
		<i>vide p. 683</i>			
Required Constant Log.,					2.78917

δA from the following Computation applied to the Observed Angles.

Observed Angles to the nearest second.			δA	Angles reduced to the time of Maximum Elongation.		
°	'	"	\dagger	°	'	"
1	47	4	40	1	47	44
1	47	9	34	1	47	43
1	47	26	17	1	47	43
1	47	29	13	1	47	42
1	47	40	4	1	47	44
1	47	41	1	1	47	42
1	47	47	0	1	47	47
1	47	45	2	1	47	47
1	47	36	10	1	47	46
1	47	27	14	1	47	41
1	47	11	33	1	47	44
1	47	3	39	1	47	42

Mean Angle at the time of Maximum Elongation,	°	'	"	1 47 44
*'s Azimuth <i>vide p. 683</i> ,				1 47 43
Azimuth of the Referring Mark West,				0 0 1

Deduction of δA .

	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	
Observed Chronometer Times...	5 58 27.6	0 25.6	7 32.6	9 36.6	16 23.6	19 59.6	26 22.6	28 58.6	37 0.6	39 19.6	47 18.6	49 15.6						
Chronometer time of Maximum Elongation,	6 24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6	24 0.6
Chronometer Intervals,	25 38	23 35	16 28	14 24	7 37	4 1	2 22	4 58	13 0	15 19	23 18	25 15						
Chronometer Intervals reduced to the decimals of a minute,	25.55	23.58	16.47	14.40	7.62	4.02	2.37	4.97	13.00	15.32	23.30	25.25						
Logs of the same,	1.40739	1.37254	1.21669	1.15836	0.88196	0.60423	0.37475	0.69636	1.11394	1.18526	1.36736	1.40226						
Repeated,	1.40739	1.37254	1.21669	1.15836	0.88196	0.60423	0.37475	0.69636	1.11394	1.18526	1.36736	1.40226						
Constant Log,	2.78917	2.78917	2.78917	2.78917	2.78917	2.78917	2.78917	2.78917	2.78917	2.78917	2.78917	2.78917						
Logs of δA ,	1.60395	1.53425	1.22255	1.10589	0.55309	1.99763	1.59867	0.18189	1.01705	1.15699	1.52358	1.59369						
δA in Seconds,	40	34	17	13	4	1	0	2	10	14	38	39						

The azimuth of the Referring Mark having been deduced by any of the preceding methods, a simple observation with any magnetic instrument is only necessary, to ascertain at once the variation of the needle, by accurately fixing the theodolite over the station dot, and taking a series of magnetic bearings to the Referring Mark. The difference between the mean of such Readings and the computed azimuth, is the required variation, which will be *East* or *West* according as the true azimuth is greater or less than the magnetic, supposing the azimuth is reckoned from North by East. Hence to obtain the true azimuth when the variation is *East*, add it to the magnetic bearing, and if *West*, subtract it. It is unnecessary to enter further into this subject beyond what is required for practical purposes. All the chief works on navigation treat of the variation of the compass in different parts of the world, and to such works the reader is referred for further information. In this country the magnetic variation is about $2\frac{1}{2}$ degrees *East*.

CHAPTER VIII.

ON THE METHODS OF DETERMINING THE LATITUDE OF A PLACE.

IN the methods of computation which have already been treated of in the preceding chapters, for the determination of the error of the chronometer and of the azimuth of the Referring Mark, the latitude of the station of observation is supposed to be given. If this element can be derived from the Great Trigonometrical Survey, the best thing which the Surveyor can do, is to use it at once, as it would be superior to any determination, which he is likely to effect for himself with the limited means at his disposal. On the other hand, instances will frequently occur of the Trigonometrical Survey not having extended to those districts, which are being traversed over by a revenue or topographical operation: in such cases the required latitudes of places, must be derived from observation alone. It is the object of this chapter to explain the method of making and computing such observations.

With this view we will suppose that on a fine clear morning the Surveyor has arrived at the origin of his operation, furnished with a theodolite, possessing a complete vertical circle, together with a chronometer and a Nautical Almanac, and that he is ignorant of the geographical position of the place where he is standing, as also of the direction of the meridian, and the error of the chronometer. Under these circumstances, the first thing he will have to execute is to put up the theodolite and make an observation upon the sun as directed in Chapter II.,

and then taking out the latitude and longitude of the place from the best map which may be within his reach, he will compute the error of the chronometer and the chronometer time of the apparent noon. This deduction will not be of a very rigorous character. This however is a circumstance which will entail no inconvenience, as the object of this process is only to ascertain the approximate time of the sun's passage over the meridian.

About quarter of an hour before the chronometer time computed as mentioned above of the apparent noon, the Surveyor will intersect the sun's upper or lower limb as may be convenient. As the apparent noon has not yet occurred, the sun will be ascending, he will therefore follow up the intersection of the selected limb until it reaches the highest elevation. When an observation has been obtained at that limit, he will read off the vertical circle of the theodolite.

This vertical reading will be the *meridional altitude* of the observed limb of the sun. It is however taken on one face, and will therefore be impregnated with the index error of the Instrument. The amount of this error may be determined in this way. Take any fixed well-defined and high terrestrial object and observe its elevation on both faces of the theodolite, half the difference between these elevations is the required index error, additive to the face which gives the *lower*, and subtractive from that which furnishes the *higher* altitude. The Index error of the instrument may be determined before or after the sun's observation as may be convenient.

When the observed altitude has been cleared of the Index error, the next corrections to be applied thereto, are refraction and parallax, the mode of computing which will be found in the appendix. After the observed altitude has been freed from the Index error refraction and parallax, it may now be reduced to the sun's centre. This reduction is thus performed. Increase or diminish the observed altitude corrected as described above by the sun's semi-diameter according as the

lower or the upper limb was intersected; the resulting arc is the required altitude of the sun's centre.

When the elevation of the sun's centre is known, it is easy to compute the latitude of the place. According as the sun's declination is South or North, add it to, or subtract it from the said elevation, the sum or difference so obtained will be an arc, the difference between which and 90° is the latitude sought.

EXAMPLE.

The sun was observed at Hatipaon on the 25th November 1838.

Observed meridian altitude of the \odot 's upper limb,	39° 8' 18"
Index Error,	+ 34
Refraction and Parallax,	- 1 5
\odot 's Semi-diameter,	- 16 14
<hr/>	
True altitude of the \odot 's centre,	38 51 33
\odot 's South declination,	20 42 15
<hr/>	
Sum,	59 33 48
<hr/>	
Latitude of Hatipaon,	30 26 12

If similar observations are made for eight or ten days in succession, and wrought up in the way described above, the mean latitude resulting, will be sufficiently accurate for the bringing up of the azimuth deductions.

But probably on the third or the fourth day, the error of the chronometer will be known with great nicety; in which case it will not be necessary for the Surveyor to limit himself to a *single* observation of the sun per day. He may, for instance, take four altitudes *before*, and four *after* the apparent noon, marking down the chronometer time of each observation. In taking the altitudes with a Theodolite, he will observe one limb first and then the other; after which the face of the instrument being reversed, he will make two other observations similar to the first. This done, he will change the face again, and observe in the same way as before. In this manner four

changes of face may be gone through during an interval of twenty or twenty-five minutes, taking care that half this interval falls on one side of the apparent noon, and half on the other. In case of no Theodolite being available, a good sextant may be used.

As to the manner of reducing these observations, it must be noted that the observed altitudes will, in the first instance, require to be corrected for the index error, and sun's semi-diameter. When this is done, the resulting elements will be the altitudes of the sun's centre. These not being observed on the meridian, will require to be reduced thereto in the following manner:—Take the difference between the chronometer time of each observation and that of the apparent noon, and reduce it to sidereal interval. Again convert this interval into space and designate the resulting quantity by δp .

The term δp for each observation being deduced, and the sun's declination (d), and the approximate latitude north (λ) of the place being known, the required correction for a given altitude may be computed by the following formulæ,—

When the declination is North.

$$x'' = \frac{2 \cos d \cos \lambda \sin^2 \frac{1}{2} \delta p}{\sin 1'' \sin(d \oslash \lambda)} *$$

When the declination is South.

$$x'' = \frac{2 \cos d \cos \lambda \sin^2 \frac{1}{2} \delta p}{\sin 1'' \sin(d + \lambda)} *$$

The correction x'' brought out in this way, will be in seconds—and when added to the given altitude will render it meridional altitude. From the meridional altitude of the sun's centre, the latitude may be computed as directed before.

As an illustration of the computation of these formulæ, take the following observations made on the Sun at Hatipaon, on

* The terms ($d \oslash \lambda$) and ($d + \lambda$) represent meridional zenith distances.

the 2nd December 1838, with Gilbert's Sextant No. 1 and Hare's Chronometer :

Index error of the Sextant = 55" to be applied negatively.

Objects Observed.	Observed.			Deduced Elements of the ☉'s centre.		
	Double Altitudes.	Chronometer Times.		Altitudes cor- rected for Index error.	Chronometer Times.	
	° ' "	h. m. s.		° ' "	h. m. s.	
☉'s L. L.	74 44 40	21 17 0		37 38 5	21 17 30	
☉'s U. L.	75 49 30	21 18 0				
☉'s U. L.	75 49 50	21 19 0		37 38 16	21 19 30	
☉'s L. L.	74 45 5	21 20 0				
☉'s L. L.	74 45 25	21 21 0		37 38 21	21 21 30	
☉'s U. L.	75 49 50	21 22 0				
☉'s U. L.	75 50 0	21 23 0		37 38 11	21 23 30	
☉'s L. L.	74 44 35	21 24 0				
☉'s L. L.	74 45 0	21 25 0		37 37 55	21 25 30	
☉'s U. L.	75 48 30	21 26 0				

Inches.

Barometer = 23.688

°

Thermometer = 49.5

In this Table the mean of the altitudes of the sun's upper and lower limbs has been taken as the elevation of the sun's centre, the chronometer time corresponding thereto being the mean of the two observed times. This is a process which is only approximately correct, the rigorous procedure as required by the rule, consisting in the separate reduction of the individual observations to the sun's centre ; a method of computation which has been dispensed with in the present instance, on account of the limited accuracy of the observed data. It ought to be remarked that when two altitudes, one taken before, and the other after the apparent noon, are combined as is done in the Table, a positive error will be produced in the result. Consequently the two observations taken under the latter circumstances will require to be corrected for semidiameter, and separately reduced.

Deduction of the foregoing observations.

Constant Log. Computed.

° ' "

☉'s South Declination,	$d = 21\ 55\ 34$	.. Cos.	1.96739
Approximate Lat. of Hatipaon. ...	$\lambda = 30\ 26\ 12$	.. Cos.	1.98560
	$d + \lambda = 52\ 21\ 46$	.. Cosec.	0.10133
L. 2 + L. Cosec. 1'			5.61546
Constant Log.			<u>5.61978</u>

	h. m. s.	h. m. s.	h. m. s.	h. m. s.	h. m. s.	
Observed Chronometer Times, ...	21 17 30	21 19 30	21 21 30	21 23 30	21 25 30	
Computed Chronometer Time of Apparent Noon,	21 20 59	21 20 59	21 20 59	21 20 59	21 20 59	
δp {	Chronometer Time, ..	0 3 29	0 1 29	0 0 31	0 2 31	0 4 31
	Siderial Time,	0 3 29.57	0 1 29.24	0 0 31.08	0 2 31.41	0 4 31.74
	Space,	0 52 23.55	0 22 18.60	0 7 46.20	0 37 51.15	0 67 56.10
$\frac{1}{2} \delta p$	0 26 12	0 11 9	0 3 53	0 18 56	0 33 58	
$\sin \frac{1}{2} \delta p$ {	7.88202	7.51100	7.05293	7.74095	7.99477
	7.88202	7.51100	7.05293	7.74095	7.99477
Constant Log.,	5.61978	5.61978	5.61978	5.61978	5.61978	
Log. x''	1.38382	0.64178	1.72564	1.10168	1.60832	
x''	+ 24"	+ 4"	+ 1"	+ 13"	+ 41"	
Observed Altitudes,	37 38 5	37 38 16	37 38 21	37 38 11	37 37 55	
Reduced Meridional Altitudes, ...	37 38 29	37 38 20	37 38 23	37 38 24	37 38 36	

Latitude of Hatipaon deduced.

Mean Meridional Altitude,	37 38 26
Refraction and Parallax,	— 53
Corrected Altitude,	37 37 33
☉'s South Declination,	21 55 34
Sum,	59 33 7
Latitude,	30 26 53

What has been said regarding the sun is likewise applicable to a star. Suppose an altitude is taken to the latter in the same manner as the former is directed to be observed. This altitude being cleared of index error and refraction, and then if necessary reduced to the meridian, the latitude may be deduced therefrom in the same way as in the case of the sun.

The observations we have described above as leading to the determination of the latitude of a place, whether made on the sun or a star, are supposed to be taken on, or near the meridian. There is a method, however, whereby the latitude may be deduced from an observation on Polaris (α Ursæ Minoris) made at any time without reference to its position with regard

to the meridian line. The elements required in this deduction are, 1st. The time of the observation, and 2nd. The observed altitude; and when these are forthcoming, the necessary computation may be easily made by the aid of the rules and tables given in the Nautical Almanac, to which the reader is referred for further information on the subject. The method is simple and may be practised with great advantage in the Revenue Survey.

Whenever, however the meridian line can be traced, the observations made thereon for the determination of latitude would be preferable to all others both in point of accuracy and facility of reduction. These observations may be made with a Theodolite in this way. Place the instrument in the plane of the meridian, and take the altitude of ten or twelve stars so selected that half the number may be situated to the North, and half to the South of the zenith, none being further off than 15° from that point. The observations must be continued for a week or ten days, the face of the instrument being reversed after each observation during the night, at the same time taking care that the same star is taken on opposite faces on two successive nights. The latitude resulting from such data would be as trustworthy as could be desired.

Suppose after the completion of the observations it is discovered that the Theodolite was not adjusted to the meridian, but was set in a plane which was inclined thereto by a small angle which we shall designate by δA . It is evident that in such a case the observed altitudes are not meridional altitudes. To make them meridional however, a correction of the following form will only require to be computed for each star, and added to the observed elevation,—

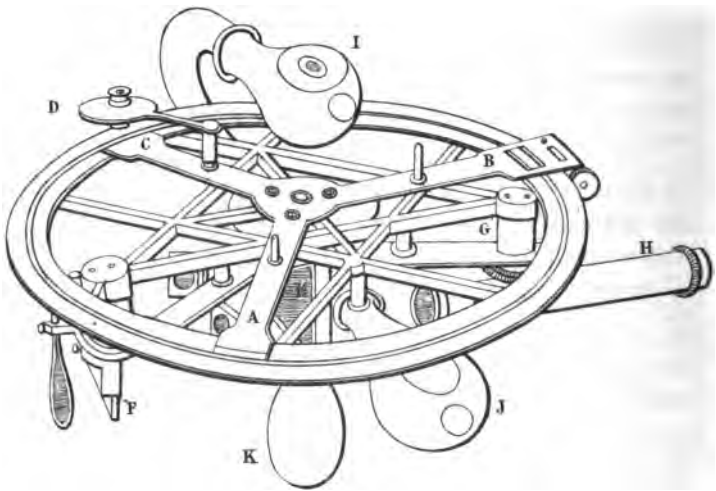
$$y'' = \frac{\delta A^2 \cos \lambda \cos a}{2 \cos d \operatorname{cosec} 1''}$$

In which expression λ stands for the approximate latitude of the place, d for the star's declination and a for the observed altitude, the resulting correction y'' being in seconds.

Another method exists for determining the latitude of a place by taking the elevations of a circumpolar star at its upper and lower culmination. When such observations are made, half the sum of the elevations cleared of index error and refraction will be the latitude required. This is a method however which cannot always be conveniently practised in this country, on account of the small altitude of the circumpolar star at its lower meridional passage, when it will be often involved in the mist which surrounds the horizon.

For observations of this nature the Reflecting Circle is an instrument which is frequently employed in India as possessing very superior qualities over the Sextant, but which having been inadvertently omitted to be noticed in its proper place in Part 2, the following description of its use and adjustments is taken from "Simms on Mathematical Instruments."

TROUGHTON'S REFLECTING CIRCLE.



The above figure represents this instrument, which in principle and use is the same as the sextant. It has three vernier readings, A B C, moving round the same centre as the index-glass, E, which is upon the opposite face of the

instrument. One of the verniers, B, carries the clamp and tangent-screw. D represents the microscope for reading the verniers ; it is similar to the one used in reading the sextant, and is adapted to each index-bar, by slipping it on a pin placed for that purpose, as shown in the figure. The horizon-glass is shown at F. The barrel, G, contains the screws for giving the up-and-down motion to the telescope ; it is put in action by turning the milled head under the barrel. H is the telescope, adapted to the instrument in a manner similar to that of the sextant. I and J are two handles fixed parallel to the plane of the circle, and a third handle, K, is screwed on at right angles to that plane, and can be transferred to the opposite face of the instrument by screwing it into the handle, I ; the use of this extra handle is for convenience in reading and in holding the instrument, when observing angles that are nearly horizontal ; it can be shifted, according as the face of the instrument is held upwards or downwards. The requisite dark glasses are attached to the framework of the circle, to be used in the same manner and for the same purposes as those of the sextant. With respect to the adjustments and application of this instrument, we cannot do better than use the words of the inventor, Mr. TROUGHTON, contained in a paper which he calls

“ Directions for observing with Troughton’s Reflecting Circle.

“ Prepare the instrument for observation by screwing the telescope into its place, adjusting the drawer to focus, and the wires parallel to the plane exactly as you do with a sextant : also set the index forwards to the rough distance of the sun and moon, or moon and star ; and holding the circle by the short handle, direct the telescope to the fainter object, and make the contact in the usual way. Now read off the degree, minute, and second, by that branch of the index to which the tangent-screw is attached ; also, the minute and second shown by the other two branches ; these give the distance taken on three different sextants ; but as yet, it is only to be considered as half an observation : what remains to be done, is to complete the whole circle, by measuring that angle on the other three sextants. Therefore set the index backwards nearly to the same distance, and reverse the plane of the instrument, by holding it by the opposite handle, and make the contact as above, and read off as before what is shown on the three several branches of the index. The mean of all six, is the true apparent distance, corresponding to the mean of the two times at which the observations were made.

“ When the objects are seen very distinctly, so that no doubt whatever remains about the contact in both sights being perfect, the above may safely be relied on as a complete set ; but if, from the haziness of the air, too much motion, or any other cause, the observations have been rendered doubtful, it will be advisable to make more : and if, at such times, so many readings should be deemed troublesome, six observations, and six readings may be conducted in the manner following : Take three successive sights forwards, exactly as is done with a sextant ; only take care to read them off on different

branches of the index : also make three observations backwards, using the same caution : a mean of these will be the distance required. When the number of sights taken forwards and backwards are unequal, a mean between the means of these taken backwards and those taken forwards will be the true angle.

“ It need hardly be mentioned, that the shades, or dark-glasses, apply like those of a sextant, for making the objects nearly, of the same brightness ; but it must be insisted on, that the telescope should, on every occasion, be raised or lowered, by its proper screw, for making them perfectly so.

“ The foregoing instructions for taking distances, apply equally for taking altitudes by the sea or artificial horizon, they being no more than distances taken in a vertical plane. Meridian altitudes cannot, however, be taken both backwards and forwards the same day, because there is not time : all therefore that can be done, is, to observe the altitude one way, and use the index-error ; but even here, you have a mean of that altitude, and this error, taken on three different sextants. Both at sea and land, where the observer is stationary, the meridian altitude should be observed forwards one day, and backwards the next, and so on alternately from day to day ; the mean of latitudes, deduced severally from such observations, will be the true latitude ; but in these there should be no application of index-error, for that being constant, the result would in some measure be vitiated thereby.

“ When both the reflected and direct images require to be darkened, as is the case when the sun’s diameter is measured and when his altitude is taken with an artificial horizon, the attached dark-glasses ought not to be used : instead of them, those which apply to the eye-end of the telescope will answer much better : the former having their errors magnified by the power of the telescope, will, in proportion to this power, and those errors, be less distinct than the latter.

“ In taking distances when the position does not vary from the vertical above thirty or forty degrees, the handles which are attached to the circle are generally most conveniently used ; but in those which incline more to the horizontal, that handle which screws into a cock on one side, and into the crooked handle on the other, will be found more applicable.

“ When the crooked handle happens to be in the way of reading one of the branches of the index, it must be removed, for the time, by taking out the finger-screw, which fastens it to the body of the circle.

“ If it should happen that two of the readings agree with each other very well, and the third differs from them, the discordant one must not on any account be omitted, but a fair mean must always be taken.

“ It should be stated, that when the angle is about thirty degrees, neither the distance of the sun and moon, nor an altitude of the sun, with the sea horizon, can be taken backwards ; because the dark-glasses at that angle prevent the reflected rays of light from falling on the index-glass ; whence it

becomes necessary, when the angle to be taken is quite unknown to observe forwards first, where the whole range is without interruption ; whereas, in that backwards, you will lose sight of the reflected image about that angle. But in such distances, where the sun is out of the question, and when his altitude is taken with an artificial horizon, (the shade being applied to the end of the telescope) that angle may be measured nearly as well as any other ; for the rays incident on the index-glass will pass through the transparent half of the horizon-glass, without much diminution of their brightness.

“ The advantages of this instrument, when compared with the sextant, are chiefly these : the observations for finding the index-error are rendered useless, all knowledge of that being put out of the question, by observing both forwards and backwards. By the same means the errors of the dark-glasses are also corrected ; for, if they increase the angle one way, they must diminish it the other way by the same quantity. This also perfectly corrects the errors of the horizon-glass, and those of the index-glass very nearly. But what is still of more consequence, the error of the centre is perfectly corrected, by reading the three branches of the index ; while this property combined with that of observing both ways, probably reduces the errors of dividing to one-sixth part of their simple value. Moreover, angles may be measured as far as one hundred and fifty degrees, consequently the sun’s double altitude may be observed when his distance from the zenith is not less than fifteen degrees ; at which altitude, the head of the observer begins to intercept the rays of light incident on the artificial horizon ; and, of course, if a greater angle could be measured, it would be of no use in this respect.

“ This instrument, in common with the sextant, requires three adjustments. First, the index-glass perpendicular to the plane of the circle. This being done by the maker, and not liable to alter, has no direct means applied to the purpose : it is known to be right, when, by looking into the index-glass, you see that part of the limb which is next you, reflected in contact with the opposite side of the limb, as one continued arc of a circle : on the contrary, when the arc appears broken, where the reflected and direct parts of the limb meet, it is a proof that it wants to be rectified. The second is, to make the horizon-glass perpendicular. This is performed by a capstan-screw, at the lower end of the frame of that glass ; and is known to be right, when, by a sweep of the index, the reflected image of any object will pass exactly over, or cover the image of that object seen directly. The third adjustment is, for making the line of collimation parallel to the plane of the circle. This is performed by two small screws, which also fasten the collar into which the telescope screws to the upright stem on which it is mounted ; this is known to be right, when the sun and moon, having a distance of one hundred and thirty degrees, or more, their limbs are brought in contact, just at the outside of that wire which is next to the circle ; and then, examining if it be the same, just at the outside of the other wire : its being so is the proof of adjustment.

CHAPTER IX.

ON LONGITUDE.

THE Longitude of a place may be defined to be an arc of the equator intercepted between the first meridian, and that passing through the given place. The selection of the first meridian from which longitudes are measured, is entirely arbitrary. The English use the meridian of the Royal Observatory at Greenwich as the first meridian, and reckon all longitudes to the east and west thereof. On the other hand, *le premier meridien* of the French Geographers passes through the Paris Observatory, which is $2^{\circ} 20' 15''$ east of the former.

The longitude of a place is as often given in space as in time, the reduction of one measure to the other, being made at the rate of 15° an hour. Thus the longitude of the Dome of the Government House in Calcutta may be indifferently stated at $88^{\circ} 23' 27''$ or 5h. 53m. 33·8s. east of Greenwich, and in this proportion of space into time, the Tables in Chapter II. have been constructed.

The reason of reckoning the longitude in time, is this; suppose of two places *A* and *B*, the time at *A* is given, it is required to determine the corresponding time at *B*. This is a problem of great astronomical importance, and when the difference of longitude between *A* and *B* is given in time, it may be easily solved in this way: According as *B* is to the east or west of *A*, add the difference of longitude to, or subtract it from, the given time at *A*, the sum or difference so obtained, will be the required time at *B*. Thus when it is 7h. 22m.

40s. P. M. in Calcutta, it will be 1h. 29m. 6·2s. P. M. at Greenwich.

On the converse operation to this process, are based the astronomical methods of determining the longitude of a place. For instance, if at any moment, the times at the stations *A* and *B* are known, the difference between them is the difference of longitude sought, *B* being east or west of *A* according as the time at *B* is greater or less than the time at *A*. The time at *B*, the Observers station, being found by any of the methods laid down in the preceding Chapters, that at *A* or the first meridian, is the required element in the determination of the problem.

These principles being premised, we cannot do better than give the following memoranda of instructions furnished by the Astronomer Royal Mr. Airy, to the Officers deputed to mark the boundary between the British Territories in America and the United States of America; which instructions duly carried into effect, will give the longitudes of places with the accuracy required for all ordinary geographical purposes.

OBSERVATIONS FOR THE ABSOLUTE LONGITUDE OF STATION.

On the Boundary Survey these were determined entirely by observing the transits of the moon, and moon culminating stars. No other method is equal to it for accuracy and simplicity combined. Though this proved to be the case, the following paper of instructions, given by Mr. Airy, the Astronomer Royal, is so valuable, that it is considered right to insert the *whole* of it, as it cannot fail to be of service to all who have to make observations for longitude.

Observations for the Absolute Longitude of one Station.

1. The observations applicable to this determination will be the following:—
 - (α) Distances of the moon from the sun, or a star.
 - (β) Transits of the moon.
 - (γ) Zenith distances of the moon.
 - (δ) Occultations of stars by the moon.*

* In former times, the lunar and solar eclipses (particularly the former) were made use of to determine the longitude of a place;—but these not being susceptible of accurate observations are no longer used for this purpose. The mode of making observations on these Phenomena are well explained in the Penny Cyclopædia “Article Longitude.”

(ϵ) Eclipses of Jupiter's satellites.

2. (a) Lunar distances.—It is necessary to combine with these, observations of the zenith distance of the moon, and of the sun, or star; and the following order will probably be found best for observation.

Several lunar distances to be taken with the utmost accuracy (noting the time of each by the standard box chronometer, whose error can be found by transits on the same evening.)

A zenith distance of the moon (noting time) which needs not to be very accurate.

A zenith distance of the star (noting time) which needs not to be very accurate.

Several lunar distances.

A zenith distance of the star.

A zenith distance of the moon.

Several lunar distances.

Taking the mean of each group of distances, and then the mean of those means, and the means of the corresponding chronometer times, it will be easy, from the observed zenith distances, to deduce the zenith distances at these same times; and thus all of observation is completed.

3. For the reduction of those distances, the accurate method only should be used.

4. It must be borne in mind that, on any night, observations ought to be made of distances from stars on both sides; that particular care should be taken to make the star sweep on the moon's limb; and that observations should be made after full moon as well as before it. In using the sextant the index error ought to be determined as near as may be to the time of observation. In using the reflecting circle, the three verniers should always be read. In using the repeating reflecting circle, the two verniers of that arm which is read should always be read.

5. It will probably be best to defer the reductions of the observations.

But if there is leisure, you may proceed with the following cautions, some of which are not usually considered by nautical computers. With the Greenwich time, by account, compute the moon's "Horizontal Parallax," from the Nautical Almanac (which is *equatorial* horizontal parallax) and "semidiameter" (which is *geocentric* semidiameter).

For the spheroidal form of the earth, multiply the equatorial horizontal parallax by $1 - e \sin^2$ latitude, or diminish it by the part expressed by $e \times \sin^2$ latitude (which in the boundary latitudes will not sensibly differ from $\frac{1}{600}$ part, or $5'$ to $6''$), and you have the true horizontal parallax, to be used in every part that follows.

Multiply the *geocentric semidiameter* by $1 + \cos$ moon's zenith distance \times sin horizontal parallax, and you have the augmented semidiameter, to be used in every part that follows.

Apply the augmented semidiameter (and also the sun's semidiameter, if the sun was the other object,) to the observed distance, additively if the nearest limbs were observed, subtractively if the opposite, and you have the observed distance of centres. Call this D .

To the moon's observed zenith distance of limb apply the augmented semidiameter, and you have the observed zenith distance of moon's centre.

To take into account fully the spheroidal form of the earth, compute the "angle of the centre" for the place by the formula $11' 25'' \times \sin^2 \text{latitude}$ (which for the boundary latitudes will not sensibly differ from $11' 25''$), and diminish the moon's zenith distance by angle of the centre $\times \cos$ azimuth from south, or increase it by angle of the centre $\times \cos$ azimuth from north (if the sun be north of the east or west). When the zenith distance is so altered, call it Z .

Do the same for sun's centre and call the result ζ . If the other object were a star, ζ is simply the zenith distance, affected by angle of the centre \times cosine of azimuth.

6. For the zenith distance ζ , add the refraction computed as usual, and (if the sun) subtract the parallax computed by the formula $8'' \cdot 7 \sin \zeta$, and the result is true zenith distance of sun or star. Call this ζ' .

For the zenith distance z , add the refraction computed as usual, and subtract the parallax computed by the formulæ, true horizontal parallax $\times \sin z$, and the result is true zenith distance of moon's centre. Call this z' .

7. Then the computation for the true distance of centres, or D' , is this :—

$$\text{Make } \cos^2 \phi = \frac{\sin \frac{z + \zeta + D}{2}, \sin \frac{z + \zeta - D}{2}, \sin z', \sin \zeta'}{\sin^2 \frac{z' + \zeta'}{2} \cdot \sin z, \sin \zeta'}$$

$$\text{Then } \sin \frac{D'}{2} = \sin \frac{z' + \zeta'}{2} \sin \phi.$$

This form of calculation is accurate.

8. When the corrected distance of centers is thus obtained, it is to be compared with the distances given for every three hours in the Nautical Almanac, and by taking proportional parts among them, the Greenwich mean solar time will be found. Then I recommend that this Greenwich mean solar time be converted into Greenwich sidereal time, and the difference between this and the sidereal time of observation at the place will be the longitude of the place.

9. (β) Transits of the moon ;—a very simple and tolerably accurate method ; but as only about eight observations can (usually) be taken in a month, and as the moon can be observed at no time but on the meridian, it

will not be safe to rely upon it, except in a residence of many months' continuation.

10. The process of observing is simply to place the transit instrument in good adjustment, and to observe transits of the moon's bright limb, of clock stars, and of stars given in the section, "Moon culminating stars" of the Nautical Almanac. Then, inferring the clock error either from the clock stars or from the moon culminating stars, and applying this clock error to the observed time of transit of the moon's limb, you have the right ascension of the moon's limb at passage.

11. To compute from this the longitude. First it must be remarked, that in the section of the Nautical Almanac, the right ascension of the bright limb only at transit at Greenwich is given; but, as the duration of semidiameter's passage is given, by adding or subtracting twice this quantity, you may obtain the right ascension of the other limb at transit at Greenwich. Thus in the following computations you will be able to collect right ascensions at Greenwich transit all for the 1 L , or all for the 2 L , according as the 1 L , or the 2 L is observed at the place. Having formed these, (if necessary) take the right ascension for the Greenwich transit corresponding to the observation, for the preceding day, for the following day, and for the lower passages which fall between them; place them in proper order, and take their differences as far as the fourth difference—thus:

	Differences.			
	1st.	2nd.	3rd.	4th.
Preceding day, A_{-3}	Δ'_1			
Lower passage preceding, A_{-1}	Δ'_0	Δ''_{-1}		
Corresponding day, A_0	Δ'_0	Δ''_0	Δ'''_{-1}	
Lower passage following, .. A_1	Δ'_1	Δ''_1	Δ''_0	Δ'''
Following day, A_2	Δ'_2			

$$\text{Form the coefficients } e = \frac{\Delta'''}{24}$$

$$\text{'' '' } d = \frac{\Delta''_1 + \Delta''_0}{12}$$

$$\text{'' '' } c = \frac{\Delta''_0}{2} - e$$

$$\text{'' '' } b = \frac{\Delta'_0 + \Delta'_1}{2} - d$$

Then the right ascension of moon's limb at transit in west longitude L will be

$$A_0 + b \times \left(\frac{L}{12^h}\right) + c \times \left(\frac{L}{12^h}\right)^2 + d \times \left(\frac{L}{12^h}\right)^3 + e \times \left(\frac{L}{12^h}\right)^4.$$

12. As the longitude of the station by account will not be greatly in error, the easiest method will probably be to assume two values for L , one five

minutes greater, and the other five minutes less, than the longitude by account (or when more accurately known, one one minute greater and one one minute

less). The logarithms of $\frac{L}{12^h}$ &c., for these two values can be prepared and

will always be ready. Then compute from the last formula the right ascension on each assumption, find the change produced by ten minutes or two minutes of longitude, and find by proportional parts what alteration must be applied to the smaller longitude, in order that the right ascension by formulæ may agree with right ascension by observation in 10.

VERY GREAT CARE must be used throughout this operation, to apply the *signs* STRICTLY ACCORDING TO THE RULES OF ALGEBRA.

13. (γ .) Longitude by zenith distances of the moon. This is a very good method, provided the observations be made not very far from 6^h sidereal time (whatever may be the season of the year). It would fail if the sidereal time were near 18^h.

Thus in spring (equinox) the most favourable time of day would be an hour or two before or after six in the afternoon.

In summer (solstice) an hour or two before or after noon.

In autumn (equinox) an hour or two before or after six in the morning.

In winter (solstice) an hour or two before or after midnight.

The age of the moon is of little importance, provided that sometimes the preceding limb, and sometimes the following limb, is observed.

14. For the observation, I recommend that the altitude and azimuth instrument be well adjusted, and that the transits of the moon's limb, in its sloping upward or downward motion, be observed over all the horizontal wires, and that the mean of these times of transit be held to apply to the observation on the middle horizontal wire. (If it is certain that the wires are truly horizontal, the instrument should be kept unmoved, if this is not certain, the horizontal tangent screw should be used to make the moon pass each wire at its middle.) Then read the microscopes and levels, reverse, and do the same again. Thus the apparent zenith distance of limb will be known with great accuracy at a certain chronometer time. The chronometer error being ascertained from observations of stars, the sidereal time will be known.

15. Compute the refraction and the parallax (the latter by the formula, true horizontal parallax \times sine apparent zenith distance of limb, corrected by the quantity angle of centre \times cosine azimuth), and applying them to the apparent zenith distance of limb (adding refraction subtracting parallax), you have geocentric zenith distance of limb. Apply to this the semidiameter as taken from the Nautical Almanac, and not augmented, and you have the geocentric zenith distance of centre.

16. The longitude by account being nearly known, assume two longitudes, one greater and one less. For each assumption, apply the longitude to the sidereal time at the place, which gives the sidereal time at Greenwich. Con-

vert this into mean solar time at Greenwich ; with this mean solar time and the hourly ephemeris of the Nautical Almanac, compute the moon's right ascension and κ . P. D. by simple proportion of the hourly change. Then proceed to find the hour angle, exactly as if it were a star, using the geocentric zenith distance of centre, the colatitude of the place, and the κ . P. D. just computed. Apply the hour angle to the right ascension, and thus obtain the computed sidereal time ; obtaining *two* computed sidereal times from the *two* assumptions of longitude, you will find (as in other cases) what correction must be applied to the smaller longitude, in order to make the computed sidereal time agree with sidereal time at the observations of the moon.

17. (δ .) Longitude by occultations of stars by the moon. Suppose the disappearance of a star behind the moon, or the reappearance of a star from behind the moon, has been observed, and the chronometer time noted (the calculation is precisely the same for disappearance or reappearance). Correct the chronometer for its error, and thus the true sidereal time at the place is found.

18. Assume two values of longitude, one greater and one less than the reputed values, and by applying these to the sidereal time, form the sidereal times at Greenwich on the two assumptions, and convert them into mean solar times at Greenwich. With these mean solar times compute (by the hourly ephemeris) the right ascension and κ . P. D. of the moon's centre on each assumption ; also the equatorial horizontal parallax and the semidiameter, and from the equatorial horizontal parallax obtain the true horizontal parallax as in 5.

19. The latitude of station to be used in the following computations is the geocentric latitude, which will be found generally by diminishing the astronomical latitude by the angle of the centre, and which in the boundary latitudes, viz. 45° to 48° , will be found by diminishing the astronomical latitude by $11' 25''$.

20. Take from the Nautical Almanac, section occultations—elements, the right ascension and κ . P. D. of the star whose occultation has been observed. From the right ascension and time find the hour angle. Put θ for the hour angle and δ for the κ . P. D. Then determine a new right ascension, θ' , and a new κ . P. D., δ' , by the following equations :—

$$\theta - \theta' = \frac{\sin \theta \times \text{true hor. par.} \times \text{cosine latitude}}{\sin \delta'}$$

$$1\text{st No.} = \frac{\sin \delta \times \sin \theta \times \text{true hor. par.} \times \text{sine latitude}}{\text{sine } \frac{1}{2} (\theta + \theta')}$$

$$2\text{nd No.} = \frac{(\theta - \theta') \times \text{sine } (\delta + \delta' - 180^\circ)}{2 \tan \frac{1}{2} (\theta + \theta')}$$

$$\delta - \delta' = 1\text{st No.} + 2\text{nd No.}$$

21. These equations are to be solved by successive substitution. Two substitutions will usually be sufficient. Thus—first assume δ' to be the same as δ , and from the first equation determine θ' . Use this in the two other equations, and you will get 1st No., 2nd No., and δ' , very nearly. Use this new value of δ in the first equation and you will get $\theta - \theta'$ much more accurately: then by means of the other two, δ' can be got still more accurately; and so on again if you think fit.

22. With this new hour angle, θ' , and the sidereal time, determine a new right ascension; then calculate the following quantity:—

Computed semidiameter of moon—

$$\sqrt{\left\{ \begin{array}{l} \delta' - \text{N. P. D. of moon's centre} \\ + \sin \delta' \sin \text{N. P. D. of moon's centre, new R. A.} - \text{R. A. of moon's centre} \end{array} \right\}^2}$$

This is to be computed on the two assumptions for longitude (which have given two right ascensions and N. P. D. of moon's centre).

23. The computed semidiameter ought to agree with the Nautical Almanac semidiameter found in 18. If neither of the two assumptions of longitude makes it do so, one of them must be altered by a proportional part of their difference, found in the same manner as in other cases where two longitudes are tried.

24. (ϵ .) Longitude by eclipses of Jupiter's satellites—a very rough method. The observation is merely to note the last instant, or the first instant (according as it is disappearance or reappearance) of the satellite. The computation is merely to correct this for chronometer error, so as to obtain sidereal time, and to compare this with the Greenwich sidereal time given in the Nautical Almanac.

25. In regard to the effects of errors of observation, the following remarks should be borne in mind:—

A certain error of time in taking a lunar distance produces that same error in the deduced longitude. An error in the measure of one second produces about two seconds of time in the longitude.

An error of one second of time in a lunar transit produces about thirty seconds' error in the longitude.

An error of one second of time in a lunar zenith distance will produce at least thirty seconds of time error in longitude, sometimes considerably more. An error of one second in zenith distance produces at least two seconds of time in longitude, sometimes considerably more.

An error of one second of time in an occultation produces one second of time in the longitude.

The same in the observations of eclipses of Jupiter's satellites.

In illustration of the part (β) transits of the moon, the following observa-

tions and calculations, made at the station of Lake Memphramagog, in Canada, are given.

The transits of the stars and the moon's bright limb, are the mean of the five wires without any correction (which is unnecessary) for azimuthal error.

LAKE MEMPHRAMAGOG, 1845.

Calculations for Longitudes from observed Lunar Transits.

Values of $(\frac{L}{12^h}) - (\frac{L}{12^h})^2$ &c., assuming the Longitudes at 4h. 48m. and 4h. 49m.

$(\frac{L}{12^h})$	^{M.} 288	Log. 288 = 2.459392	$(\frac{L}{12^h})$	^{M.} 289	Log. 289 = 2.460897
	720	" 720 = 2.857332		720	" 720 = 2.857332
		1.602060			1.603565
$(\frac{L}{12^h})^2$	=	1.204120	$(\frac{L}{12^h})^2$	=	1.207130
$(\frac{L}{12^h})^3$	=	2.806180	$(\frac{L}{12^h})^3$	=	2.810695
$(\frac{L}{12^h})^4$	=	2.408240	$(\frac{L}{12^h})^4$	=	2.414260

August 14, 1845.

μ' Sagittarii.			A. S. C. 2125.				
	H.	M.	S.		H.	M.	S.
Tt.	18	14	49.46	Tt.	18	30	41.1
R. A.	18	4	33.87	R. A.	18	20	25.89
			10 15.59				10 15.21
			10 15.21				
2)			80				
			10 15.40				

Preceding Day,...	...	...	H.	M.	S.	M.	S.
			17	55	40.57	+ 32	31.50
Lower Passage Preceding,			18	28	12.07	- 6.52	S.
Corresponding Day,...	...	...	19	0	37.05	+ 32	24.98
						-17.95	+ 2.10
Lower Passage Following,			19	32	44.08	+ 32	7.03
						-27.28	-9.33
Following Day,...	...	...	20	4	23.83	+ 31	39.75

$$e = \frac{\Delta'''}{24} = + \frac{2.10}{24} = + .087$$

$$d = \frac{\Delta'' + \Delta'''}{12} = - \frac{20.76}{12} = - 1.730$$

$$c = \frac{\Delta''}{2} - e = - \frac{17.95}{2} - e = - 8.975 - (+ .087) = - 9.062$$

$$b = \frac{\Delta' + \Delta''}{2} - d = + \frac{64.32.01}{2} - d = + 32.16.005 - (-1.73) = + 32.17.735$$

1937.735

$ \begin{aligned} & \text{R. A.} = \begin{array}{r} \text{H. M. S.} \\ 19 \quad 0 \quad 37\cdot05 \\ + 1937\cdot735 \\ \hline \end{array} \\ & + b \times \left(\frac{L}{12^h}\right) = + 0 \quad 12 \quad 55\cdot90 \\ & + c \times \left(\frac{L}{12^h}\right)^2 = - 0 \quad 0 \quad 1\cdot45 \\ & + d \times \left(\frac{L}{12^h}\right)^3 = - 0 \quad 0 \quad 0\cdot11 \\ & + e \times \left(\frac{L}{12^h}\right)^4 = + 0 \quad 0 \quad 0\cdot00 \quad 0\cdot087 = \frac{2}{2} \end{aligned} $	$ \begin{aligned} & \text{R.A.} = \begin{array}{r} \text{H. M. S.} \\ 19 \quad 0 \quad 37\cdot05 \\ = 3\cdot287294 \\ \hline \end{array} \\ & + 0 \quad 12 \quad 57\cdot78 = 2\cdot890859 \\ & - 0 \quad 0 \quad 1\cdot46 = 0\cdot164354 \\ & - 0 \quad 0 \quad 0\cdot11 = 0\cdot048741 \\ & + 0 \quad 0 \quad 0\cdot00 = \frac{2}{2} \end{aligned} $
	$ \begin{array}{r} \hline 1\cdot602060 \\ \hline 2\cdot899354 \\ - 9\cdot062 = 0\cdot957224 \\ \hline 1\cdot204120 \\ \hline 0\cdot161344 \\ - 1\cdot730 = 0\cdot238046 \\ \hline 2\cdot806180 \\ \hline 1\cdot044226 \\ \hline 19 \quad 13 \quad 30\cdot58 \\ 19 \quad 13 \quad 31\cdot78 \\ \hline 0 \quad 0 \quad 01\cdot20 \\ \hline \end{array} $
D's R. A. at	$ \begin{array}{r} \hline 19 \quad 13 \quad 33\cdot26 \\ 19 \quad 13 \quad 30\cdot58 \\ \hline 0 \quad 0 \quad 02\cdot68 \\ \hline \end{array} $

s.	s.	s.
2·68	: 60	:: 1·20
	1·20	
2·68)	72·00	(26·86
	536	
	1840	
	1608	
	2320	
	2144	
	1760	

H.	M.	S.
4	48	0
0	0	26·86
4	48	26·86

Longitude = $\begin{array}{r} \text{H. M. S.} \\ 4 \quad 48 \quad 26\cdot86^* \end{array}$

In addition to the foregoing methods, it may be useful to lay down the process of determining the difference of longitude between two places by a chronometer. Suppose *A* and *B* to be these two places. At *A* find the error and rate of the chronometer, and then transport it to *B*. At the latter station take a *time* observation with the same chronometer; the time at *B* being known, and that at *A* being deduced from the in-

* From the Corps Papers and Memoirs on Military Subjects of the Royal and East India Company's Engineers, vol. I, pp. 311, 318.

dication of the chronometer, the difference between these two elements is the difference of the longitude required.

In practice when a chronometer is carried over-land, it cannot be relied upon in furnishing a very accurate difference of longitude between two places, as its rate becomes liable to irregular variations from the jolting, attendant on its transport. But the uncertainty which arises from the employment of one chronometer may often be got rid of by the use of several, when the mean of all the results may be assumed as the true difference of longitude, between the two stations of observation.

In exploring new countries, or in accompanying armies on a foreign expedition, the time, necessary for making longitude observations, cannot be spared; in such cases the difference of longitude between two places may be determined by means of a route survey combined with Azimuth observations in the following manner :

It ought to be premised that the object of such a survey is not so much to lay down the road, as to fix with accuracy the positions of distant places; with this view the stations selected along the route, should be as few as possible, and *not less than one mile apart*. The line of the road may be followed whenever stations can be fixed thereon fulfilling these conditions. But as this is a circumstance which is not always obtainable in practice, the road sometimes deviating from a straight course, and passing through towns which obstruct a distant view in front; the trace of the route in such cases may be carried out of the direction of the road, so as to pass clear of the obstructing towns, which, if required, may be connected with the trace aforesaid by offsets, or by subsidiary routes executed with different or inferior instruments.

There ought to be at least three perambulators for executing the linear measurement, their errors being previously ascertained by rolling them over a distance fixed by a trigonometrical operation. Two perambulators would be insufficient, for in

case discrepant results occurring, they will remain unaccounted for, the perambulator which has gone wrong, being detectable only by the employment of a third. At the commencement of the survey the perambulators being set to dissimilar readings, they will read differently all the way, and thus prove an effective check on the erroneous reading and noting of the distances.

A 7-inch Theodolite will be the best instrument for making the necessary angular measurement.

The distances and angles of the route will require to be measured according to the method of the Ray Trace Survey. In addition to these measurements it will be necessary to take *latitude* and *Azimuth observations* at the origin, and in the vicinities of large towns, which are about one degree or sixty miles asunder, and also at the terminus. With good instruments both the latitude and Azimuth in each instance may be ascertained with sufficient accuracy in two or three days.

When all these observations are completed, the reduction of the route may be performed in the following manner :

Let *A* and *B* be two consecutive stations on the route where astronomical observations have been made. It is clear first that the direct distance from *A* to *B* may be deduced according to the Ray Trace Method; 2nd, that with this distance, and the observed latitude and Azimuth at *A*, the latitude of *B*, the back Azimuth of *A*, and the difference of longitude between *A* and *B* may be computed as shewn in Chapter 18, Part 3; and that lastly a similar deduction with reference to *A*, may be made from the observed elements at *B*.

When these deductions are finished, it will be seen that *A* and *B* will each possess two latitudes, one derived from observation, and the other from computation; and that likewise there will be two computed differences of longitude between these stations. If these results are accordant, it may be taken as a proof of the accuracy of the work. But as an agreement of this kind will rarely occur in practice, the best mode of

dealing with the discordant data, is to take in every instance the observed latitudes and the mean between the two computed differences of longitude, as the true values of these elements.

The limits A and B of the route being fixed, the intermediate points may be adjusted according to the method explained at pp. 381, 383.

In the Appendix will be found a list containing the latitudes and longitudes of many well-known fixed places, derived from the Great Trigonometrical Survey of India, which will afford the best information to the Surveyor, in the prosecution of any Survey operations within the limits of the District specified. They have been arranged alphabetically according to Districts, and the three Presidencies separately detailed.

Appendix.

TABLE A.
For correcting Gunter's Chains of 100 Links or 66 Feet.

1 Inch.		2 Inch.		3 Inch.		4 Inch.		5 Inch.		6 Inch.		7 Inch.		8 Inch.		9 Inch.		11 Inch.	
Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.	Links.	Chains.
1	0.126	1	0.253	1	0.379	1	0.505	1	0.631	1	0.758	1	0.884	1	1.010	1	1.136	1	1.262
	0.253	0.505	0.758	0.758	1.515	1.515	1.010	1.262	1.515	1.768	1.768	2.020	2.272	2.272	2.524	2.524	2.776	2.776	3.028
5	0.618	0.505	1.010	1.515	1.515	2.020	2.020	2.525	2.525	3.030	3.030	3.535	3.535	4.040	4.040	4.545	4.545	5.050	5.050
	0.758	1.515	1.515	2.020	2.020	2.525	2.525	3.030	3.030	3.535	3.535	4.040	4.040	4.545	4.545	5.050	5.050	5.555	5.555
	0.884	1.768	1.768	2.273	2.273	2.778	2.778	3.283	3.283	3.788	3.788	4.293	4.293	4.798	4.798	5.303	5.303	5.808	5.808
	1.010	2.020	2.020	3.030	3.030	4.040	4.040	5.050	5.050	6.060	6.060	7.070	7.070	8.080	8.080	9.090	9.090	10.100	10.100
10	1.263	1.010	2.020	3.030	3.030	4.040	4.040	5.050	5.050	6.060	6.060	7.070	7.070	8.080	8.080	9.090	9.090	10.100	10.100
	1.515	3.030	2.778	4.545	4.545	6.060	6.060	7.575	7.575	9.090	9.090	10.605	10.605	12.120	12.120	13.635	13.635	15.150	15.150
	1.768	3.535	4.293	5.050	5.050	6.565	6.565	8.080	8.080	9.595	9.595	11.110	11.110	12.625	12.625	14.140	14.140	15.655	15.655
	2.020	4.040	4.798	6.060	6.060	8.080	8.080	10.100	10.100	12.120	12.120	14.140	14.140	16.160	16.160	18.180	18.180	20.200	20.200
15	2.146	4.293	4.798	6.399	6.399	8.499	8.499	10.599	10.599	12.699	12.699	14.799	14.799	16.899	16.899	18.999	18.999	21.099	21.099
	2.272	4.545	5.050	6.565	6.565	8.665	8.665	10.765	10.765	12.865	12.865	14.965	14.965	17.065	17.065	19.165	19.165	21.265	21.265
	2.524	5.050	5.555	7.070	7.070	9.170	9.170	11.270	11.270	13.370	13.370	15.470	15.470	17.570	17.570	19.670	19.670	21.770	21.770
20	2.898	5.796	6.399	8.499	8.499	10.599	10.599	12.699	12.699	14.799	14.799	16.899	16.899	18.999	18.999	21.099	21.099	23.199	23.199
	3.024	6.044	6.549	8.649	8.649	10.749	10.749	12.849	12.849	14.949	14.949	17.049	17.049	19.149	19.149	21.249	21.249	23.349	23.349
	3.270	6.549	7.054	9.149	9.149	11.249	11.249	13.349	13.349	15.449	15.449	17.549	17.549	19.649	19.649	21.749	21.749	23.849	23.849
	3.516	7.054	7.559	9.649	9.649	11.749	11.749	13.849	13.849	15.949	15.949	18.049	18.049	20.149	20.149	22.249	22.249	24.349	24.349
	3.762	7.559	8.064	10.149	10.149	12.249	12.249	14.349	14.349	16.449	16.449	18.549	18.549	20.649	20.649	22.749	22.749	24.849	24.849
	4.008	8.064	8.569	10.649	10.649	12.749	12.749	14.849	14.849	16.949	16.949	19.049	19.049	21.149	21.149	23.249	23.249	25.349	25.349
	4.254	8.569	9.074	11.149	11.149	13.249	13.249	15.349	15.349	17.449	17.449	19.549	19.549	21.649	21.649	23.749	23.749	25.849	25.849
	4.500	9.074	9.579	11.649	11.649	13.749	13.749	15.849	15.849	17.949	17.949	20.049	20.049	22.149	22.149	24.249	24.249	26.349	26.349
	4.746	9.579	10.084	12.149	12.149	14.249	14.249	16.349	16.349	18.449	18.449	20.549	20.549	22.649	22.649	24.749	24.749	26.849	26.849
	5.000	10.084	10.589	12.649	12.649	14.749	14.749	16.849	16.849	18.949	18.949	21.049	21.049	23.149	23.149	25.249	25.249	27.349	27.349
	5.256	10.589	11.094	13.149	13.149	15.249	15.249	17.349	17.349	19.449	19.449	21.549	21.549	23.649	23.649	25.749	25.749	27.849	27.849
	5.512	11.094	11.599	13.649	13.649	15.749	15.749	17.849	17.849	19.949	19.949	22.049	22.049	24.149	24.149	26.249	26.249	28.349	28.349
	5.768	11.599	12.104	14.149	14.149	16.249	16.249	18.349	18.349	20.449	20.449	22.549	22.549	24.649	24.649	26.749	26.749	28.849	28.849
	6.024	12.104	12.609	14.649	14.649	16.749	16.749	18.849	18.849	20.949	20.949	23.049	23.049	25.149	25.149	27.249	27.249	29.349	29.349
	6.280	12.609	13.114	15.149	15.149	17.249	17.249	19.349	19.349	21.449	21.449	23.549	23.549	25.649	25.649	27.749	27.749	29.849	29.849
	6.536	13.114	13.619	15.649	15.649	17.749	17.749	19.849	19.849	21.949	21.949	24.049	24.049	26.149	26.149	28.249	28.249	30.349	30.349
	6.792	13.619	14.124	16.149	16.149	18.249	18.249	20.349	20.349	22.449	22.449	24.549	24.549	26.649	26.649	28.749	28.749	30.849	30.849
	7.048	14.124	14.629	16.649	16.649	18.749	18.749	20.849	20.849	22.949	22.949	25.049	25.049	27.149	27.149	29.249	29.249	31.349	31.349
	7.304	14.629	15.134	17.149	17.149	19.249	19.249	21.349	21.349	23.449	23.449	25.549	25.549	27.649	27.649	29.749	29.749	31.849	31.849
	7.560	15.134	15.639	17.649	17.649	19.749	19.749	21.849	21.849	23.949	23.949	26.049	26.049	28.149	28.149	30.249	30.249	32.349	32.349
	7.816	15.639	16.144	18.149	18.149	20.249	20.249	22.349	22.349	24.449	24.449	26.549	26.549	28.649	28.649	30.749	30.749	32.849	32.849
	8.072	16.144	16.649	18.649	18.649	20.749	20.749	22.849	22.849	24.949	24.949	27.049	27.049	29.149	29.149	31.249	31.249	32.949	32.949
	8.328	16.649	17.154	19.149	19.149	21.249	21.249	23.349	23.349	25.449	25.449	27.549	27.549	29.649	29.649	31.749	31.749	33.049	33.049
	8.584	17.154	17.659	19.649	19.649	21.749	21.749	23.849	23.849	25.949	25.949	28.049	28.049	30.149	30.149	32.249	32.249	33.149	33.149
	8.840	17.659	18.164	20.149	20.149	22.249	22.249	24.349	24.349	26.449	26.449	28.549	28.549	30.649	30.649	32.749	32.749	33.249	33.249
	9.096	18.164	18.669	20.649	20.649	22.749	22.749	24.849	24.849	26.949	26.949	29.049	29.049	31.149	31.149	33.249	33.249	33.349	33.349
	9.352	18.669	19.174	21.149	21.149	23.249	23.249	25.349	25.349	27.449	27.449	29.549	29.549	31.649	31.649	33.349	33.349	33.449	33.449
	9.608	19.174	19.679	21.649	21.649	23.749	23.749	25.849	25.849	27.949	27.949	30.049	30.049	32.149	32.149	33.449	33.449	33.549	33.549
	9.864	19.679	20.184	22.149	22.149	24.249	24.249	26.349	26.349	28.449	28.449	30.549	30.549	32.649	32.649	33.549	33.549	33.649	33.649
	10.120	20.184	20.689	22.649	22.649	24.749	24.749	26.849	26.849	28.949	28.949	31.049	31.049	33.149	33.149	33.649	33.649	33.749	33.749
	10.376	20.689	21.194	23.149	23.149	25.249	25.249	27.349	27.349	29.449	29.449	31.549	31.549	33.249	33.249	33.749	33.749	33.849	33.849
	10.632	21.194	21.699	23.649	23.649	25.749	25.749	27.849	27.849	29.949	29.949	31.649	31.649	33.349	33.349	33.849	33.849	33.949	33.949
	10.888	21.699	22.204	24.149	24.149	26.249	26.249	28.349	28.349	30.449	30.449	31.749	31.749	33.449	33.449	33.949	33.949	34.049	34.049
	11.144	22.204	22.709	24.649	24.649	26.749	26.749	28.849	28.849	30.549	30.549	31.849	31.849	33.549	33.549	34.049	34.049	34.149	34.149
	11.400	22.709	23.214	25.149	25.149	27.249	27.249	29.349	29.349	31.449	31.449	31.949	31.949	33.649	33.649	34.149	34.149	34.249	34.249
	11.656	23.214	23.719	25.649	25.649	27.749	27.749	29.849	29.849	31.949	31.949	32.049	32.049	33.749	33.749	34.249	34.249	34.349	34.349
	11.912	23.719	24.224	26.149	26.149	28.249	28.249	30.349	30.349	32.049	32.049	32.149	32.149	33.849	33.849	34.349	34.349	34.449	34.449
	12.168	24.224	24.729	26.649	26.649	28.749	28.749	30.849	30.849	32.149	32.149	32.249	32.249	33.949	33.949	34.449	34.449	34.549</	

T A B L E
For reducing Chains
Calculated

Chains.	Decimal parts.	10	20	30	40	50	60	70	80	90	100	110
1	0·0125	0·1375	0·2625	0·3875	0·5125	0·6375	0·7625	0·8875	1·0125	1·1375	1·2625	1·3875
2	·0250	·1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000
3	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125
4	·0500	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250
5	·0625	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375
6	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500
7	·0875	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625
8	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750
9	·1125	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625	·4875
10	·1250	·2500	·3750	·5000	·6250	·7500	·8750	1·0000	·1250	·2500	·3750	·5000
	250	260	270	280	290	300	310	320	330	340	350	360
1	3·1375	3·2625	3·3875	3·5125	3·6375	3·7625	3·8875	4·0125	4·1375	4·2625	4·3875	4·5125
2	·1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000	·5250
3	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375
4	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500
5	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625
6	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750
7	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875
8	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000
9	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625	·4875	·6125
10	·2500	·3750	·5000	·6250	·7500	·8750	4·0000	·1250	·2500	·3750	·5000	·6250
	500	510	520	530	540	550	560	570	580	590	600	610
1	6·2625	6·3875	6·5125	6·6375	6·7625	6·8875	7·0125	7·1375	7·2625	7·3875	7·5125	7·6375
2	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000	·5250	·6500
3	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375	·6625
4	·3000	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500	·6750
5	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625	·6875
6	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7000
7	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125
8	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250
9	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625	·4875	·6125	·7375
10	·3750	·5000	·6250	·7500	·8750	7·0000	·1250	·2500	·3750	·5000	·6250	·7500
	750	760	770	780	790	800	810	820	830	840	850	860
1	9·3875	9·5125	9·6375	9·7625	9·8875	10·0125	10·1375	10·2625	10·3875	10·5125	10·6375	10·7625
2	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000	·5250	·6500	·7750
3	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875
4	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500	·6750	·8000
5	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625	·6875	·8125
6	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250
7	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125	·8375
8	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500
9	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625	·4875	·6125	·7375	·8625
10	·5000	·6250	·7500	·8750	10·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750

B.
the Decimal Parts of a Mile.
 W. R. M. Graham.

120	130	140	150	160	170	180	190	200	210	220	230	240
1·5125	1·6375	1·7625	1·8875	2·0125	2·1375	2·2625	2·3875	2·5125	2·6375	2·7625	2·8875	3·0125
·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250
·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375
·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500
·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625
·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750
·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875
·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000
·6125	·7375	·8625	·9875	·1125	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125
·6250	·7500	·8750	2·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750	3·0000	·1250
370	380	390	400	410	420	430	440	450	460	470	480	490
4·6375	4·7625	4·8875	5·0125	5·1375	5·2625	5·3875	5·5125	5·6375	5·7625	5·8875	6·0125	6·1375
·6500	·7750	·9000	·0250	·1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500
·6625	·7875	·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625
·6750	·8000	·9250	·0500	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500	·1750
·6875	·8125	·9375	·0625	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875
·7000	·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000
·7125	·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125
·7250	·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250
·7375	·8625	·9875	·1125	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375
·7500	·8750	5·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750	6·0000	·1250	·2500
620	630	640	650	660	670	680	690	700	710	720	730	740
7·7625	7·8875	8·0125	8·1375	8·2625	8·3875	8·5125	8·6375	8·7625	8·8875	9·0125	9·1375	9·2625
·7750	·9000	·0250	·1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750
·7875	·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875
·8000	·9250	·0500	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000
·8125	·9375	·0625	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125
·8250	·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250
·8375	·9625	·0875	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375
·8500	·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500
·8625	·9875	·1125	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625
·8750	8·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750	9·0000	·1250	·2500	·3750
870	880	890	900	910	920	930	940	950	960	970	980	990
9·8875	11·0125	11·1375	11·2625	11·3875	11·5125	11·6375	11·7625	11·8875	12·0125	12·1375	12·2625	12·3875
·9000	·0250	·1500	·2750	·4000	·5250	·6500	·7750	·9000	·0250	·1500	·2750	·4000
·9125	·0375	·1625	·2875	·4125	·5375	·6625	·7875	·9125	·0375	·1625	·2875	·4125
·9250	·0500	·1750	·3000	·4250	·5500	·6750	·8000	·9250	·0500	·1750	·3000	·4250
·9375	·0625	·1875	·3125	·4375	·5625	·6875	·8125	·9375	·0625	·1875	·3125	·4375
·9500	·0750	·2000	·3250	·4500	·5750	·7000	·8250	·9500	·0750	·2000	·3250	·4500
·9625	·0875	·2125	·3375	·4625	·5875	·7125	·8375	·9625	·0875	·2125	·3375	·4625
·9750	·1000	·2250	·3500	·4750	·6000	·7250	·8500	·9750	·1000	·2250	·3500	·4750
·9875	·1125	·2375	·3625	·4875	·6125	·7375	·8625	·9875	·1125	·2375	·3625	·4875
10·0000	·1250	·2500	·3750	·5000	·6250	·7500	·8750	12·0000	·1250	·2500	·3750	·5000

TABLE C.

Showing the Length of a Degree, Minute, and Second, of Latitude and Longitude, for every Degree of the Quadrant, the Compression of the Earth being assumed $3\frac{1}{4}$.

Dist. from Equator.	LATITUDE.			LONGITUDE.			Dist. from Equator.	LATITUDE.			LONGITUDE.		
	Lengths in Feet, of a							Lengths in Feet, of a					
	Degree.	Minute.	Second.	Degree.	Minute.	Second.		Degree.	Minute.	Second.	Degree.	Minute.	Second.
0	362759	6046-0	100-76	365147	6085-8	101-43	45	364547	6075-8	101-26	258623	4310-4	71-84
1	362761	6046-0	100-76	365091	6084-8	101-41	46	364610	6076-8	101-27	254064	4234-7	70-58
2	362764	6046-1	100-77	364925	6082-1	101-37	47	364673	6077-9	101-29	249467	4157-8	69-30
3	362769	6046-2	100-77	364849	6077-5	101-29	48	364735	6078-9	101-31	244744	4079-1	67-99
4	362776	6046-4	100-77	364263	6071-0	101-18	49	364797	6079-9	101-32	240007	4000-1	66-67
5	362785	6046-4	100-77	363767	6062-8	101-05	50	364859	6081-0	101-34	235166	3919-4	65-32
6	362796	6046-6	100-77	363161	6052-7	100-88	51	364920	6082-0	101-36	230252	3837-5	63-98
7	362808	6046-8	100-77	362445	6040-7	100-68	52	364981	6083-0	101-38	225267	3754-4	62-57
8	362826	6047-1	100-78	361619	6027-0	100-45	53	365042	6084-0	101-40	220213	3670-2	61-17
9	362844	6047-4	100-78	360683	6011-4	100-19	54	365102	6085-0	101-41	215091	3584-8	59-75
10	362864	6047-7	100-79	359637	5994-0	99-90	55	365161	6086-0	101-42	209903	3498-4	58-31
11	362886	6048-1	100-79	358490	5974-7	99-58	56	365219	6087-0	101-44	204650	3394-2	56-57
12	362910	6048-5	100-80	357217	5953-6	99-23	57	365276	6087-9	101-46	199334	3305-6	55-09
13	362937	6048-9	100-81	355846	5930-8	98-55	58	365332	6088-9	101-48	193957	3215-9	53-60
14	362966	6049-4	100-82	354368	5906-1	98-44	59	365387	6089-8	101-50	188520	3125-3	52-09
15	362997	6049-9	100-83	352783	5879-7	97-99	60	365441	6090-7	101-52	183025	3060-4	50-54
16	363029	6050-5	100-84	351099	5851-5	97-53	61	365495	6091-6	101-53	177473	2957-9	49-30
17	363063	6051-0	100-85	349290	5821-5	97-02	62	365548	6092-5	101-55	171866	2864-4	47-74
18	363099	6051-6	100-86	347385	5789-7	96-50	63	365599	6093-3	101-56	166206	2770-1	46-17
19	363137	6052-3	100-87	345374	5756-2	96-94	64	365649	6094-1	101-57	160495	2674-9	44-58
20	363177	6052-9	100-88	343258	5721-0	96-55	65	365697	6094-9	101-58	154736	2578-9	42-98
21	363219	6053-6	100-89	341038	5684-0	94-73	66	365743	6095-7	101-59	148929	2432-1	41-37
22	363262	6054-4	100-91	338715	5645-2	94-09	67	365788	6096-5	101-60	143076	2284-6	39-74
23	363306	6055-1	100-92	336289	5604-8	93-41	68	365832	6097-2	101-61	137178	2226-3	38-10
24	363351	6055-8	100-93	333760	5562-7	92-71	69	365875	6097-9	101-63	131236	2187-3	36-45
25	363397	6056-6	100-94	331130	5518-8	91-98	70	365917	6098-6	101-64	125252	2087-5	34-79
26	363445	6057-4	100-96	328400	5473-3	91-22	71	365957	6099-3	101-65	119229	1967-1	33-12
27	363495	6058-2	100-97	325570	5426-2	90-44	72	365995	6099-9	101-66	113171	1886-2	31-44
28	363546	6059-1	100-98	322641	5377-3	89-62	73	366032	6100-5	101-67	107079	1784-6	29-74
29	363599	6060-0	100-99	319613	5326-9	88-78	74	366068	6101-1	101-68	100954	1682-6	28-04
30	363653	6060-9	101-01	316487	5274-8	87-91	75	366097	6101-6	101-69	94798	1580-0	26-33
31	363707	6061-8	101-03	313265	5221-1	87-02	76	366128	6102-1	101-71	88613	1476-9	24-61
32	363762	6062-7	101-03	309948	5165-8	86-10	77	366157	6102-8	101-71	82400	1373-3	22-89
33	363818	6063-6	101-05	306537	5108-9	85-15	78	366184	6103-1	101-72	76162	1268-4	21-16
34	363875	6064-6	101-07	303032	5050-5	84-17	79	366208	6103-5	101-72	69900	1165-0	19-42
35	363933	6065-5	101-09	299435	4990-6	83-18	80	366230	6103-8	101-73	63616	1060-3	17-67
36	363992	6066-5	101-10	295746	4929-1	82-15	81	366250	6104-2	101-73	57310	955-2	15-92
37	364052	6067-5	101-11	291968	4866-1	81-10	82	366268	6104-5	101-74	50986	840-8	14-16
38	364113	6068-5	101-13	288098	4801-6	80-03	83	366284	6104-7	101-74	44646	744-1	12-40
39	364174	6069-6	101-15	284142	4735-7	78-83	84	366298	6105-0	101-75	38293	638-2	10-64
40	364235	6070-6	101-17	280098	4668-3	77-50	85	366309	6105-1	101-75	31929	532-1	8-87
41	364297	6071-6	101-19	275969	4599-5	76-66	86	366318	6105-3	101-75	25555	426-0	7-10
42	364359	6072-6	101-21	271756	4529-3	75-49	87	366325	6105-4	101-75	19173	319-5	5-33
43	364421	6073-7	101-22	267460	4457-7	74-29	88	366330	6105-6	101-76	12795	213-1	3-55
44	364484	6074-7	101-24	263082	4384-7	73-08	89	366333	6105-6	101-76	6393	106-6	1-78
45	364547	6075-8	101-26	258623	4310-4	71-84	90	366335	6105-6	101-76	0	0	0

NOTE.—The degrees of latitude are calculated for the latitudes of their middle points.

TABLE D.

For Converting Chains and Links into Feet and Decimals of Feet.

Links.	Chains.									Dec. of feet.	Links.	Chains.									Dec. of feet.		
	0	1	2	3	4	5	6	7	8			9	0	1	2	3	4	5	6	7		8	9
	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.			Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.	Ft.			
0	0	66	132	198	264	330	396	462	528	594	.00	50	33	99	165	231	297	363	429	495	561	627	.00
1	0	66	132	198	264	330	396	462	528	594	.06	51	33	99	165	231	297	363	429	495	561	627	.06
2	1	67	133	199	265	331	397	463	529	595	.12	52	34	100	166	232	298	364	430	496	562	628	.12
3	1	67	133	199	265	331	397	463	529	595	.18	53	34	100	166	232	298	364	430	496	562	628	.18
4	2	68	134	200	266	332	398	464	530	596	.24	54	35	101	167	233	299	365	431	497	563	629	.24
5	2	68	135	201	267	333	399	465	531	597	.30	55	36	102	168	234	300	366	432	498	564	630	.30
6	3	69	135	201	267	333	399	465	531	597	.36	56	36	102	168	234	300	366	432	498	564	630	.36
7	4	70	136	202	268	334	400	466	532	598	.42	57	37	103	169	235	301	367	433	499	565	631	.42
8	4	70	137	203	269	335	401	467	533	599	.48	58	38	104	170	236	302	368	434	500	566	632	.48
9	5	71	138	203	269	335	401	467	533	599	.54	59	38	104	170	236	302	368	434	500	566	632	.54
10	5	71	138	204	270	336	402	468	534	600	.60	60	39	105	171	237	303	369	435	501	567	633	.60
11	7	73	139	205	271	337	403	469	535	601	.66	61	40	106	172	238	304	370	436	502	568	634	.66
12	7	73	139	205	271	337	403	469	535	601	.72	62	40	106	172	238	304	370	436	502	568	634	.72
13	8	74	141	206	272	338	404	470	536	602	.78	63	41	107	173	239	305	371	437	503	569	635	.78
14	8	74	141	207	273	339	405	471	537	603	.84	64	42	108	174	240	306	372	438	504	570	636	.84
15	9	75	142	207	273	339	405	471	537	603	.90	65	42	108	174	240	306	372	438	504	570	636	.90
16	10	76	143	208	274	340	406	472	538	604	.96	66	43	109	175	241	307	373	439	505	571	637	.96
17	11	77	143	209	275	341	407	473	539	605	.02	67	44	110	176	242	308	374	440	506	572	638	.02
18	11	77	144	209	275	341	407	473	539	605	.08	68	44	110	176	242	308	374	440	506	572	638	.08
19	12	78	145	210	276	342	408	474	540	606	.14	69	45	111	177	243	309	375	441	507	573	639	.14
20	13	79	145	211	277	343	409	475	541	607	.20	70	46	112	178	244	310	376	442	508	574	640	.20
21	13	79	146	211	277	343	409	475	541	607	.26	71	46	112	178	244	310	376	442	508	574	640	.26
22	14	80	147	212	278	344	410	476	542	608	.32	72	47	113	179	245	311	377	443	509	575	641	.32
23	15	81	147	213	279	345	411	477	543	609	.38	73	48	114	180	246	312	378	444	510	576	642	.38
24	15	81	148	213	279	345	411	477	543	609	.44	74	48	114	180	246	312	378	444	510	576	642	.44
25	16	82	149	214	280	346	412	478	544	610	.50	75	49	115	181	247	313	379	445	511	577	643	.50
26	17	83	149	215	281	347	413	479	545	611	.56	76	50	116	182	248	314	380	446	512	578	644	.56
27	17	83	150	215	281	347	413	479	545	611	.62	77	50	116	182	248	314	380	446	512	578	644	.62
28	18	84	151	216	282	348	414	480	546	612	.68	78	51	117	183	249	315	381	447	513	579	645	.68
29	19	85	151	217	283	349	415	481	547	613	.74	79	52	118	184	250	316	382	448	514	580	646	.74
30	19	85	152	217	283	349	415	481	547	613	.80	80	52	118	184	250	316	382	448	514	580	646	.80
31	20	86	153	218	284	350	416	482	548	614	.86	81	53	119	185	251	317	383	449	515	581	647	.86
32	21	87	153	219	285	351	417	483	549	615	.92	82	54	120	186	252	318	384	450	516	582	648	.92
33	21	87	154	219	285	351	417	483	549	615	.98	83	54	120	186	252	318	384	450	516	582	648	.98
34	22	88	155	220	286	352	418	484	550	616	.04	84	55	121	187	253	319	385	451	517	583	649	.04
35	23	89	155	221	287	353	419	485	551	617	.10	85	56	122	188	254	320	386	452	518	584	650	.10
36	23	89	156	221	287	353	419	485	551	617	.16	86	56	122	188	254	320	386	452	518	584	650	.16
37	24	90	157	222	288	354	420	486	552	618	.22	87	57	123	189	255	321	387	453	519	585	651	.22
38	25	91	157	223	289	355	421	487	553	619	.28	88	58	124	190	256	322	388	454	520	586	652	.28
39	25	91	158	223	289	355	421	487	553	619	.34	89	58	124	190	256	322	388	454	520	586	652	.34
40	26	92	159	224	290	356	422	488	554	620	.40	90	59	125	191	257	323	389	455	521	587	653	.40
41	27	93	159	225	291	357	423	489	555	621	.46	91	60	126	192	258	324	390	456	522	588	654	.46
42	27	93	160	225	291	357	423	489	555	621	.52	92	60	126	192	258	324	390	456	522	588	654	.52
43	28	94	161	326	292	358	424	490	556	622	.58	93	61	127	193	259	325	391	457	523	589	655	.58
44	28	95	161	327	293	359	425	491	557	623	.64	94	62	128	194	260	326	392	458	524	590	656	.64
45	29	95	162	227	293	359	425	491	557	623	.70	95	62	128	194	260	326	392	458	524	590	656	.70
46	30	96	163	228	294	360	426	492	558	624	.76	96	63	129	195	261	327	393	459	525	591	657	.76
47	31	97	163	229	295	361	427	493	559	625	.82	97	64	130	196	262	328	394	460	526	592	658	.82
48	31	97	164	229	295	361	427	493	559	625	.88	98	64	130	196	262	328	394	460	526	592	658	.88
49	32	98	165	230	296	362	428	494	560	626	.94	99	65	131	197	263	329	395	461	527	593	659	.94
50	33	99	165	231	297	363	429	495	561	627	.00	100	66	132	198	264	330	396	462	528	594	660	.00

TABLE E.
Atmospherical Refractions.

App. Altitude.	Refr. B. 30 Th. 60°	Diff. for 1' Alt.	Diff. for + 1 B.	Diff. for - 1° Fa.	App. Altitude.	Refr. B. 30 Th. 60°	Diff. for 1' Alt.	Diff. for + 1 B.	Diff. for - 1° Fa.
D. M.	M. S.	S.	S.	S.	D. M.	M. S.	S.	S.	S.
0. 0	33.51	11,7	74	3,1	4. 0	11.52	2,2	24,1	1,70
5	32.53	11,3	71	7,6	10	11.30	2,1	23,4	1,64
10	31.58	10,9	69	7,3	20	11.10	2,0	22,7	1,58
15	31. 5	10,5	67	7,0	30	10.50	1,9	22,0	1,53
20	30.13	10,1	65	6,7	40	10.32	1,8	21,3	1,48
25	29.24	9,7	63	6,4	50	10.15	1,7	20,7	1,43
30	28.37	9,4	61	6,1	5. 0	9.58	1,6	20,1	1,38
35	27.61	9,0	59	5,9	10	9.42	1,5	19,6	1,34
40	27. 6	8,7	58	5,6	20	9.27	1,5	19,1	1,30
45	26.24	8,4	56	5,4	30	9.11	1,4	18,6	1,26
50	25.43	8,0	55	5,1	40	8.58	1,3	18,1	1,22
55	25. 3	7,7	53	4,9	50	8.45	1,3	17,6	1,19
1. 0	24.25	7,4	52	4,7	6. 0	8.32	1,2	17,2	1,15
5	23.48	7,1	50	4,6	10	8.20	1,2	16,8	1,11
10	23.13	6,9	49	4,5	20	8. 9	1,1	16,4	1,09
15	22.40	6,6	48	4,4	30	7.58	1,1	16,0	1,06
20	22. 8	6,3	46	4,2	40	7.47	1,0	15,7	1,03
25	21.37	6,1	45	4,0	50	7.37	1,0	15,3	1,00
30	21. 7	5,9	44	3,9	7. 0	7.27	1,0	15,0	,98
35	20.38	5,7	43	3,8	10	7.17	,9	14,6	,95
40	20.10	5,5	42	3,6	20	7. 8	,9	14,3	,93
45	19.43	5,3	40	3,5	30	6.59	,8	14,1	,91
50	19.17	5,1	39	3,4	40	6.51	,8	13,8	,89
55	18.52	4,9	39	3,3	50	6.43	,8	13,5	,87
2. 0	18.29	4,8	38	3,2	8. 0	6.35	,7	13,3	,85
5	18. 5	4,6	37	3,1	10	6.28	,7	13,1	,83
10	17.43	4,4	36	3,0	20	6.21	,7	12,8	,82
15	17.21	4,3	36	2,9	30	6.14	,7	12,6	,80
20	17. 0	4,1	35	2,8	40	6. 7	,7	12,3	,79
25	16.40	4,0	34	2,8	50	6. 0	,6	12,1	,77
30	16.21	3,9	33	2,7	9. 0	5.54	,6	11,9	,76
35	16. 2	3,7	33	2,7	10	5.47	,6	11,7	,74
40	15.43	3,6	32	2,6	20	5.41	,6	11,5	,73
45	15.25	3,5	32	2,5	30	5.36	,6	11,3	,71
50	15. 8	3,4	31	2,4	40	5.30	,5	11,1	,71
55	14.51	3,3	30	2,3	50	5.25	,5	11,0	,70
3. 0	14.35	3,2	30	2,3	10. 0	5.20	,5	10,8	,69
5	14.19	3,1	29	2,2	10	5.15	,5	10,6	,67
10	14. 4	3,0	29	2,2	20	5.10	,5	10,4	,65
15	13.50	2,9	28	2,1	30	5. 5	,5	10,2	,64
20	13.35	2,8	28	2,1	40	5. 0	,5	10,1	,63
25	13.21	2,7	27	2,0	50	4.56	,4	9,9	,62
30	13. 7	2,7	27	2,0	11. 0	4.51	,4	9,8	,60
35	12.53	2,6	26	2,0	10	4.47	,4	9,6	,59
40	12.41	2,5	26	1,9	20	4.43	,4	9,5	,58
45	12.28	2,4	25	1,9	30	4.39	,4	9,4	,57
50	12.16	2,4	25	1,9	40	4.35	,4	9,2	,56
55	12. 8	2,3	25	1,8	50	4.31	,4	9,1	,55

TABLE E.
Atmospherical Refractions.

App. Altitude.	Refr. B. 30 Th. 50°	Diff. for 1' Alt.	Diff. for + 1 B.	Diff. for - 1° Fa.	App. Altitude.	Refr. B. 30 Th. 50°	Diff. for 1' Alt.	Diff. for + 1 B.	Diff. for - 1° Fa.
D. M.	M. S.	S.	S.	S.	D.	M. S.	S.	S.	S.
12. 0	4.28,1	,38	8,00	,556	42	1. 4,6	,038	2,16	,130
10	4.24,4	,37	8,86	,548	43	1. 2,4	,036	2,09	,125
20	4.20,8	,36	8,74	,541	44	1. 0,3	,034	2,02	,120
30	4.17,3	,35	8,63	,533	45	58,1	,034	1,94	,117
40	4.13,9	,33	8,51	,524	46	56,1	,033	1,88	,112
50	4.10,7	,32	8,41	,517	47	54,2	,032	1,81	,108
					48	52,3	,031	1,75	,104
					49	50,5	,030	1,69	,101
13. 0	4. 7,5	,31	8,30	,509	50	48,8	,029	1,63	,097
10	4. 4,4	,31	8,20	,503	51	47,1	,028	1,58	,094
20	4. 1,4	,30	8,10	,496	52	45,4	,027	1,52	,090
30	3.58,4	,30	8,00	,490	53	43,8	,026	1,47	,088
40	3.55,5	,29	7,89	,482	54	42,2	,026	1,41	,085
50	3.52,6	,29	7,79	,476					
14. 0	3.49,9	,28	7,70	,469	55	40,8	,025	1,36	,082
10	3.47,1	,28	7,61	,464	56	39,3	,025	1,31	,079
20	3.44,4	,27	7,52	,458	57	37,8	,025	1,26	,076
30	3.41,8	,26	7,43	,453	58	36,4	,024	1,22	,073
40	3.39,2	,26	7,34	,448	59	35,0	,024	1,17	,070
50	3.36,7	,25	7,26	,444					
15. 0	3.34,3	,24	7,18	,439	60	33,6	,023	1,12	,067
30	3.27,3	,22	6,95	,424	61	32,3	,022	1,08	,065
16. 0	3.20,6	,21	6,73	,411	62	31,0	,022	1,04	,062
30	3.14,4	,20	6,51	,399	63	29,7	,021	,99	,060
17. 0	3. 8,5	,19	6,31	,386	64	28,4	,021	,95	,057
30	3. 2,9	,18	6,12	,374					
18. 0	2.57,6	,17	5,96	,362	65	27,2	,020	,91	,055
19. 0	2.47,7	,16	5,61	,340	66	25,9	,020	,87	,052
					67	24,7	,020	,83	,050
					68	23,5	,020	,79	,047
					69	22,4	,020	,75	,045
20	2.38,7	,15	5,31	,322	70	21,2	,020	,71	,043
21	2.30,5	,13	5,04	,305	71	19,9	,020	,67	,040
22	2.23,2	,12	4,79	,290	72	18,8	,019	,63	,038
23	2.16,5	,11	4,57	,276	73	17,7	,018	,60	,036
24	2.10,1	,10	4,35	,264	74	16,6	,018	,56	,033
25	2. 4,2	,09	4,16	,252					
26	1.58,8	,09	3,97	,241	75	15,5	,018	,52	,031
27	1.53,8	,08	3,81	,230	76	14,4	,018	,48	,029
28	1.49,1	,08	3,65	,219	77	13,4	,017	,45	,027
29	1.44,7	,07	3,50	,209	78	12,3	,017	,41	,025
					79	11,2	,017	,38	,023
30	1.40,5	,07	3,36	,201					
31	1.36,6	,06	3,23	,193	80	10,2	,017	,34	,021
32	1.33,0	,06	3,11	,186	81	9,2	,017	,31	,018
33	1.29,5	,06	2,99	,179	82	8,2	,017	,27	,016
34	1.26,1	,05	2,88	,173	83	7,1	,017	,24	,014
35	1.23,0	,05	2,78	,167	84	6,1	,017	,20	,012
36	1.20,0	,05	2,68	,161					
37	1.17,1	,05	2,58	,155	85	5,1	,017	,17	,010
38	1.14,4	,05	2,49	,149	86	4,1	,017	,14	,008
39	1.11,8	,04	2,40	,144	87	3,1	,017	,10	,006
					88	2,0	,017	,07	,004
40	1. 9,3	,04	2,32	,139	89	1,0	,017	,03	,002
41	1. 6,9	,04	2,24	,134					

TABLE F.
Parallax of the Sun.

Altitude	January.	February and December.	March and November.	April and October.	May and September.	June and August.	July.
0	"	"	"	"	"	"	"
4	8-95	8-93	8-87	8-80	8-72	8-67	8-65
8	8-93	8-91	8-85	8-78	8-70	8-65	8-63
12	8-85	8-84	8-79	8-71	8-64	8-58	8-57
16	8-75	8-73	8-68	8-61	8-54	8-48	8-47
20	8-60	8-58	8-53	8-46	8-39	8-34	8-32
24	8-41	8-39	8-34	8-27	8-20	8-15	8-13
28	8-18	8-16	8-10	8-04	7-97	7-92	7-91
32	7-90	7-88	7-84	7-77	7-70	7-65	7-64
36	7-59	7-57	7-53	7-46	7-40	7-36	7-34
40	7-24	7-22	7-18	7-12	7-06	7-02	7-00
44	6-88	6-84	6-80	6-74	6-69	6-64	6-63
48	6-44	6-42	6-39	6-33	6-28	6-24	6-23
52	5-99	5-98	5-94	5-89	5-84	5-80	5-79
56	5-51	5-51	5-48	5-42	5-37	5-34	5-33
58	5-01	4-99	4-96	4-92	4-88	4-85	4-84
60	4-74	4-73	4-70	4-66	4-63	4-60	4-59
62	4-47	4-46	4-43	4-40	4-36	4-33	4-32
64	4-20	4-19	4-17	4-13	4-10	4-07	4-06
66	3-92	3-91	3-89	3-86	3-82	3-80	3-79
68	3-64	3-63	3-61	3-58	3-55	3-53	3-52
70	3-35	3-34	3-32	3-30	3-27	3-25	3-24
72	3-06	3-05	3-03	3-01	2-98	2-97	2-96
74	2-77	2-76	2-74	2-72	2-70	2-68	2-68
76	2-47	2-46	2-45	2-43	2-41	2-39	2-38
78	2-17	2-16	2-15	2-13	2-11	2-10	2-10
80	1-55	1-55	1-54	1-53	1-52	1-51	1-50
84	0-94	0-93	0-93	0-92	0-91	0-91	0-90
86	0-62	0-62	0-62	0-61	0-61	0-61	0-60
88	0-31	0-31	0-31	0-31	0-31	0-30	0-30
90	0-00	0-00	0-00	0-00	0-00	0-00	0-00

TABLE G.
For Reversing Angles.

1'	2'	3'	4'	5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'	17'	18'	19'	20'	21'	22'	23'	24'	25'	26'	27'	28'	29'	30'		
59	58	57	56	55	54	53	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38	37	36	35	34	33	32	31	30		
0°	358°	20°	330°	40°	319°	60°	299°	80°	279°	100°	259°	120°	239°	140°	219°	160°	199°														
1	358	21	338	41	318	61	298	81	278	101	258	121	238	141	218	161	198														
2	357	22	337	42	317	62	297	82	277	102	257	122	237	142	217	162	197														
3	356	23	336	43	316	63	296	83	276	103	256	123	236	143	216	163	196														
4	355	24	335	44	315	64	295	84	275	104	255	124	235	144	215	164	195														
5	354	25	334	45	314	65	294	85	274	105	254	125	234	145	214	165	194														
6	353	26	333	46	313	66	293	86	273	106	253	126	233	146	213	166	193														
7	352	27	332	47	312	67	292	87	272	107	252	127	232	147	212	167	192														
8	351	28	331	48	311	68	291	88	271	108	251	128	231	148	211	168	191														
9	350	29	330	49	310	69	290	89	270	109	250	129	230	149	210	169	190														
10	349	30	329	50	309	70	289	90	269	110	249	130	229	150	209	170	189														
11	348	31	328	51	308	71	288	91	268	111	248	131	228	151	208	171	188														
12	347	32	327	52	307	72	287	92	267	112	247	132	227	152	207	172	187														
13	346	33	326	53	306	73	286	93	266	113	246	133	226	153	206	173	186														
14	345	34	325	54	305	74	285	94	265	114	245	134	225	154	205	174	185														
15	344	35	324	55	304	75	284	95	264	115	244	135	224	155	204	175	184														
16	343	36	323	56	303	76	283	96	263	116	243	136	223	156	203	176	183														
17	342	37	322	57	302	77	282	97	262	117	242	137	222	157	202	177	182														
18	341	38	321	58	301	78	281	98	261	118	241	138	221	158	201	178	181														
19	340	39	320	59	300	79	280	99	260	119	240	139	220	159	200	179	180														

TABLE H.

Comparative Scale of Fahrenheit's, Reaumur's and the Centigrade Thermometers.

EQUIVALENTS TO FAHRENHEIT'S THERMOMETER.											
Deg. Fahrt.	Deg. Reaum.	Deg. Centigr.	Deg. Fahrt.	Deg. Reaum.	Deg. Centigr.	Deg. Fahrt.	Deg. Reaum.	Deg. Centigr.	Deg. Fahrt.	Deg. Reaum.	Deg. Centigr.
-1			50	8°	10°	110	34·67	48·33	170	61·33	76·67
2	·044	·056	51	8·44	10·56	111	35·11	48·89	171	61·78	77·22
3	·089	·111	52	8·89	11·11	112	35·56	44·44	172	62·22	77·78
4	·133	·167	53	9·33	11·67	113	36	46	173	62·68	78·33
5	·178	·222	54	9·78	12·22	114	36·44	46·56	174	63·11	78·89
6	·222	·278	55	10·22	12·78	115	36·89	46·11	175	63·56	79·44
7	·267	·333	56	10·67	13·33	116	37·33	46·67	176	64	80
8	·311	·389	57	11·11	13·89	117	37·78	47·22	177	64·44	80·56
9	·356	·444	58	11·56	14·44	118	38·22	47·78	178	64·89	81·11
10	·400	·500	59	12	15	119	38·67	48·33	179	65·33	81·67
0	14·22	17·78	60	12·44	15·56	120	39·11	48·89	180	65·78	82·22
1	13·78	17·22	61	12·89	16·11	121	39·56	46·44	181	66·22	82·78
2	13·33	16·67	62	13·33	16·67	122	40	50	182	66·67	83·33
3	12·89	16·11	63	13·78	17·22	123	40·44	50·56	183	67·11	83·89
4	12·44	15·56	64	14·22	17·78	124	40·89	51·11	184	67·56	84·44
5	12	15	65	14·67	18·33	125	41·33	51·67	185	68	85
6	11·56	14·44	66	15·11	18·89	126	41·78	52·22	186	68·44	85·56
7	11·11	13·89	67	15·56	19·44	127	42·22	52·78	187	68·89	86·11
8	10·67	13·33	68	16	20	128	42·67	53·33	188	69·33	86·67
9	10·22	12·78	69	16·44	20·56	129	43·11	53·89	189	69·78	87·22
10	9·78	12·22	70	16·89	21·11	130	43·56	54·44	190	70·22	87·78
11	9·33	11·67	71	17·33	21·67	131	44	55	191	70·67	88·33
12	8·89	11·11	72	17·78	22·22	132	44·44	55·56	192	71·11	88·89
13	8·44	10·56	73	18·22	22·78	133	44·89	56·11	193	71·56	89·44
14	8	10	74	18·67	23·33	134	45·33	56·67	194	72	90
15	7·56	9·44	75	19·11	23·89	135	45·78	57·22	195	72·44	90·56
16	7·11	8·89	76	19·56	24·44	136	46·22	57·78	196	72·89	91·11
17	6·67	8·33	77	20	25	137	46·67	58·33	197	73·33	91·67
18	6·22	7·78	78	20·44	25·56	138	47·11	58·89	198	73·78	92·22
19	5·78	7·22	79	20·89	26·11	139	47·56	59·44	199	74·22	92·78
20	5·33	6·67	80	21·33	26·67	140	48	60	200	74·67	93·33
21	4·89	6·11	81	21·78	27·22	141	48·44	60·56	201	75·11	93·89
22	4·44	5·56	82	22·22	27·78	142	48·89	61·11	202	75·56	94·44
23	4	5	83	22·67	28·33	143	49·33	61·67	203	76	95
24	3·56	4·44	84	23·11	28·89	144	49·78	62·22	204	76·44	95·56
25	3·11	3·89	85	23·56	29·44	145	50·22	62·78	205	76·89	96·11
26	2·67	3·33	86	24	30	146	50·67	63·33	206	77·33	96·67
27	2·22	2·78	87	24·44	30·56	147	51·11	63·89	207	77·78	97·22
28	1·78	2·22	88	24·89	31·11	148	51·56	64·44	208	78·22	97·78
29	1·33	1·67	89	25·33	31·67	149	52	65	209	78·67	98·33
30	0·89	1·11	90	25·78	32·22	150	52·44	65·56	210	79·11	98·89
31	0·44	0·56	91	26·22	32·78	151	52·89	66·11	211	79·56	99·44
32	0	0	92	26·67	33·33	152	53·33	66·67	212	80	100
33	+ 0·44	+ 0·56	93	27·11	33·89	153	53·78	67·22	213	80·44	100·56
34	+ 0·89	+ 1·11	94	27·56	34·44	154	54·22	67·78	214	80·89	101·11
35	1·33	1·67	95	28	35	155	54·67	68·33	215	81·33	101·67
36	1·78	2·22	96	28·44	35·56	156	55·11	68·89	216	81·78	102·22
37	2·22	2·78	97	28·89	36·11	157	55·56	69·44	217	82·22	102·78
38	2·67	3·33	98	29·33	36·67	158	56	70	218	82·67	103·33
39	3·11	3·89	99	29·78	37·22	159	56·44	70·56	219	83·11	103·89
40	3·56	4·44	100	30·22	37·78	160	56·89	71·11	220	83·56	104·44
41	4	5	101	30·67	38·33	161	57·33	71·67	221	84	105
42	4·44	5·56	102	31·11	38·89	162	57·78	72·22	222	84·44	105·56
43	4·89	6·11	103	31·56	39·44	163	58·22	72·78	223	84·89	106·11
44	5·33	6·67	104	32	40	164	58·67	73·33	224	85·33	106·67
45	5·78	7·22	105	32·44	40·56	165	59·11	73·89	225	85·78	107·22
46	6·22	7·78	106	32·89	41·11	166	59·56	74·44	226	86·22	107·78
47	6·67	8·33	107	33·33	41·67	167	60	75	227	86·67	108·33
48	7·11	8·89	108	33·78	42·22	168	60·44	75·56	228	87·11	108·89
49	7·56	9·44	109	34·22	42·78	169	60·89	76·11	229	87·56	109·44
50	8	10	110	34·67	43·33	170	61·33	76·67	230	88	110

TABLE I.

For converting Intervals of Sidereal Time into Equivalent Intervals of Mean Solar Time.

HOURS.			MINUTES.			SECONDS.			
Hours of Sidereal Time.	Equivalents in Mean Time	Minutes of Sidereal Time.	Equivalents in Mean Time.	Minutes of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	
1	h m s 0 59 50.1704	1	m s 0 59.8363	31	m s 30 54.9214	1	s 0.9973	31	s 30.9154
2	1 59 40.3409	2	1 59.6723	32	31 54.7576	2	1.9945	32	31.9126
3	2 59 30.5113	3	2 59.5085	33	32 54.5937	3	2.9918	33	32.9099
4	3 59 20.6818	4	3 59.3447	34	33 54.4299	4	3.9891	34	33.9072
5	4 59 10.8522	5	4 59.1809	35	34 54.2661	5	4.9864	35	34.9045
6	5 59 1.0226	6	5 59.0170	36	35 54.1023	6	5.9838	36	35.9017
7	6 58 51.1931	7	6 58.8532	37	36 53.9384	7	6.9809	37	36.8990
8	7 58 41.3635	8	7 58.6894	38	37 53.7746	8	7.9782	38	37.8963
9	8 58 31.5340	9	8 58.5256	39	38 53.6108	9	8.9754	39	38.8935
10	9 58 21.7044	10	9 58.3617	40	39 53.4470	10	9.9727	40	39.8908
11	10 58 11.8748	11	10 58.1979	41	40 53.2831	11	10.9700	41	40.8881
12	11 58 2.0453	12	11 58.0341	42	41 53.1193	12	11.9672	42	41.8853
13	12 57 52.2157	13	12 57.8708	43	42 52.9555	13	12.9645	43	42.8826
14	13 57 42.3862	14	13 57.7064	44	43 52.7917	14	13.9618	44	43.8799
15	14 57 32.5566	15	14 57.5426	45	44 52.6278	15	14.9591	45	44.8772
16	15 57 22.7270	16	15 57.3788	46	45 52.4640	16	15.9563	46	45.8744
17	16 57 12.8975	17	16 57.2150	47	46 52.3002	17	16.9536	47	46.8717
18	17 57 3.0679	18	17 57.0511	48	47 52.1364	18	17.9509	48	47.8690
19	18 56 53.2384	19	18 56.8873	49	48 51.9725	19	18.9481	49	48.8662
20	19 56 43.4088	20	19 56.7235	50	49 51.8087	20	19.9454	50	49.8635
21	20 56 33.5792	21	20 56.5597	51	50 51.6449	21	20.9427	51	50.8608
22	21 56 23.7497	22	21 56.3958	52	51 51.4810	22	21.9399	52	51.8580
23	22 56 13.9201	23	22 56.2320	53	52 51.3172	23	22.9372	53	52.8553
24	23 56 4.0906	24	23 56.0682	54	53 51.1534	24	23.9345	54	53.8526
		25	24 55.9044	55	54 50.9896	25	24.9318	55	54.8499
		26	25 55.7405	56	55 50.8257	26	25.9290	56	55.8471
		27	26 55.5767	57	56 50.6619	27	26.9263	57	56.8444
		28	27 55.4129	58	57 50.4981	28	27.9236	58	57.8417
		29	28 55.2490	59	58 50.3343	29	28.9208	59	58.8389
		30	29 55.0852	60	59 50.1704	30	29.9181	60	59.8362

TABLE I.

For Converting Intervals of Sidereal Time into Equivalent Intervals of Mean Solar Time.

FRACTIONS OF A SECOND.						
Seconds of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.	Seconds of Sidereal Time.	Equivalents in Mean Time.	Remarks.
0-01	^s 0-00997	0-34	^s 0-33907	0-67	^s 0-66817	
0-02	0-01995	0-35	0-34804	0-68	0-67814	
0-03	0-02992	0-36	0-35702	0-69	0-68812	
0-04	0-03989	0-37	0-36599	0-70	0-69809	
0-05	0-04986	0-38	0-37496	0-71	0-70806	
0-06	0-05983	0-39	0-38393	0-72	0-71803	
0-07	0-06981	0-40	0-39291	0-73	0-72801	
0-08	0-07978	0-41	0-40188	0-74	0-73798	
0-09	0-08975	0-42	0-41085	0-75	0-74795	
0-10	0-09973	0-43	0-41983	0-76	0-75793	
0-11	0-10970	0-44	0-42880	0-77	0-76790	
0-12	0-11967	0-45	0-43777	0-78	0-77787	
0-13	0-12965	0-46	0-44674	0-79	0-78784	
0-14	0-13962	0-47	0-45572	0-80	0-79782	
0-15	0-14959	0-48	0-46469	0-81	0-80779	
0-16	0-15956	0-49	0-47366	0-82	0-81776	
0-17	0-16954	0-50	0-48264	0-83	0-82773	
0-18	0-17951	0-51	0-49161	0-84	0-83771	
0-19	0-18948	0-52	0-50058	0-85	0-84768	
0-20	0-19945	0-53	0-50955	0-86	0-85765	
0-21	0-20943	0-54	0-51853	0-87	0-86762	
0-22	0-21940	0-55	0-52750	0-88	0-87760	
0-23	0-22937	0-56	0-53647	0-89	0-88757	
0-24	0-23934	0-57	0-54544	0-90	0-89754	
0-25	0-24932	0-58	0-55442	0-91	0-90752	
0-26	0-25929	0-59	0-56339	0-92	0-91749	
0-27	0-26926	0-60	0-57236	0-93	0-92746	
0-28	0-27924	0-61	0-58133	0-94	0-93743	
0-29	0-28921	0-62	0-59031	0-95	0-94741	
0-30	0-29918	0-63	0-59928	0-96	0-95738	
0-31	0-30915	0-64	0-60825	0-97	0-96735	
0-32	0-31913	0-65	0-61723	0-98	0-97732	
0-33	0-32910	0-66	0-62620	0-99	0-98730	

This Table is useful for the conversion of Sidereal into Mean Solar Time.

Mean Solar Time required = Mean Time at the preceding Sidereal Noon + the Equivalent to the given Sidereal Time.

EXAMPLE.—To convert 21h 10m 56s Sidereal Time at Greenwich, January 2, 1849, into Mean Time.

Mean Time at the preceding Sidereal Noon, viz. ...	January	1	5	15	3	24
For Sidereal Intervals.	10	0	50	0	58	0
						20
						56
						33
						58
						9
						58
						46
						86
						58

The Sum is the Mean Time required, January 2 2 22 25 62

TABLE J.

For converting Intervals of Mean Solar Time into Equivalent Intervals of Sidereal Time.

HOURS.			MINUTES.			SECONDS.			
Hours of Mean Time.	Equivalents in Sidereal Time.	Minutes of Mean Time.	Equivalents in Sidereal Time.	Minutes of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	
1	h m s 1 0 9·8565	1	m s 1 0·1643	31	m s 31 5·0925	1	s 1·0027	31	s 31·0640
2	2 0 19·7130	2	2 0·3286	32	32 5·2568	2	2·0055	32	32·0876
3	3 0 29·5694	3	3 0·4928	33	33 5·4211	3	3·0082	33	33·0904
4	4 0 39·4259	4	4 0·6571	34	34 5·5853	4	4·0110	34	34·0931
5	5 0 49·2824	5	5 0·8214	35	35 5·7496	5	5·0137	35	35·0958
6	6 0 59·1388	6	6 0·9857	36	36 5·9139	6	6·0164	36	36·0986
7	7 1 8·9953	7	7 1·1499	37	37 6·0782	7	7·0192	37	37·1013
8	8 1 18·8518	8	8 1·3142	38	38 6·2424	8	8·0219	38	38·1040
9	9 1 28·7083	9	9 1·4785	39	39 6·4067	9	9·0246	39	39·1068
10	10 1 38·5647	10	10 1·6428	40	40 6·5710	10	10·0274	40	40·1095
11	11 1 48·4212	11	11 1·8070	41	41 6·7353	11	11·0301	41	41·1123
12	12 1 58·2777	12	12 1·9713	42	42 6·8995	12	12·0329	42	42·1150
13	13 2 8·1342	13	13 2·1356	43	43 7·0638	13	13·0356	43	43·1177
14	14 2 17·9906	14	14 2·2998	44	44 7·2281	14	14·0383	44	44·1205
15	15 2 27·8471	15	15 2·4641	45	45 7·3924	15	15·0411	45	45·1232
16	16 2 37·7036	16	16 2·6284	46	46 7·5566	16	16·0438	46	46·1259
17	17 2 47·5600	17	17 2·7927	47	47 7·7209	17	17·0465	47	47·1287
18	18 2 57·4165	18	18 2·9569	48	48 7·8852	18	18·0493	48	48·1314
19	19 3 7·2730	19	19 3·1212	49	49 8·0495	19	19·0520	49	49·1342
20	20 3 17·1295	20	20 3·2855	50	50 8·2137	20	20·0548	50	50·1369
21	21 3 26·9859	21	21 3·4498	51	51 8·3780	21	21·0575	51	51·1396
22	22 3 36·8424	22	22 3·6140	52	52 8·5423	22	22·0602	52	52·1424
23	23 3 46·6989	23	23 3·7783	53	53 8·7066	23	23·0630	53	53·1451
24	24 3 56·5554	24	24 3·9426	54	54 8·8708	24	24·0657	54	54·1479
		25	25 4·1069	55	55 9·0351	25	25·0685	55	55·1506
		26	26 4·2711	56	56 9·1994	26	26·0712	56	56·1533
		27	27 4·4354	57	57 9·3637	27	27·0739	57	57·1561
		28	28 4·5997	58	58 9·5279	28	28·0767	58	58·1588
		29	29 4·7640	59	59 9·6922	29	29·0794	59	59·1615
		30	30 4·9282	60	60 9·8565	30	30·0821	60	60·1643

TABLE J.

For converting Intervals of Mean Solar Time into Equivalent Intervals of Sidereal Time.

FRACTIONS OF A SECOND.																														
Seconds of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.	Seconds of Mean Time.	Equivalents in Sidereal Time.	Remarks.																								
0-01	^s 0-01003	0-34	^s 0-34093	0-67	^s 0-67183	<p><i>This Table is useful for the conversion of Mean Solar into Sidereal Time.</i></p> <p>Sidereal Time required = Sidereal Time at the preceding Mean Noon + the Equivalent to the given Mean Time.</p> <p>EXAMPLE.—To convert 2h 22m 25s-63 Mean Time at Greenwich, January 2, 1849, into Sidereal Time.</p> <table style="margin-left: auto; margin-right: auto;"> <tr> <td>Sidereal Time at the preceding Mean Noon, viz. January 2, ...</td> <td>18</td> <td>48</td> <td>1-66</td> </tr> <tr> <td>For Mean Intervals.</td> <td>23</td> <td>0</td> <td>19-71</td> </tr> <tr> <td>Sidereal Intervals,</td> <td>25</td> <td>3-63</td> <td>25-07</td> </tr> <tr> <td></td> <td>0-63</td> <td>0-63</td> <td></td> </tr> <tr> <td colspan="3"></td> <td>The Sum is the Sidereal Time required,</td> </tr> <tr> <td colspan="3"></td> <td>21 10 50-88</td> </tr> </table>	Sidereal Time at the preceding Mean Noon, viz. January 2, ...	18	48	1-66	For Mean Intervals.	23	0	19-71	Sidereal Intervals,	25	3-63	25-07		0-63	0-63					The Sum is the Sidereal Time required,				21 10 50-88
Sidereal Time at the preceding Mean Noon, viz. January 2, ...	18	48	1-66																											
For Mean Intervals.	23	0	19-71																											
Sidereal Intervals,	25	3-63	25-07																											
	0-63	0-63																												
			The Sum is the Sidereal Time required,																											
			21 10 50-88																											
0-02	0-02006	0-35	0-35096	0-68	0-68186																									
0-03	0-03008	0-36	0-36099	0-69	0-69189																									
0-04	0-04011	0-37	0-37101	0-70	0-70192																									
0-05	0-05014	0-38	0-38104	0-71	0-71194																									
0-06	0-06016	0-39	0-39107	0-72	0-72197																									
0-07	0-07019	0-40	0-40110	0-73	0-73200																									
0-08	0-08022	0-41	0-41112	0-74	0-74203																									
0-09	0-09025	0-42	0-42115	0-75	0-75205																									
0-10	0-10027	0-43	0-43118	0-76	0-76208																									
0-11	0-11030	0-44	0-44120	0-77	0-77211																									
0-12	0-12033	0-45	0-45123	0-78	0-78214																									
0-13	0-13036	0-46	0-46126	0-79	0-79216																									
0-14	0-14038	0-47	0-47129	0-80	0-80219																									
0-15	0-15041	0-48	0-48131	0-81	0-81222																									
0-16	0-16044	0-49	0-49134	0-82	0-82225																									
0-17	0-17047	0-50	0-50137	0-83	0-83227																									
0-18	0-18049	0-51	0-51140	0-84	0-84230																									
0-19	0-19052	0-52	0-52142	0-85	0-85233																									
0-20	0-20055	0-53	0-53145	0-86	0-86235																									
0-21	0-21057	0-54	0-54148	0-87	0-87238																									
0-22	0-22060	0-55	0-55151	0-88	0-88241																									
0-23	0-23063	0-56	0-56153	0-89	0-89244																									
0-24	0-24066	0-57	0-57156	0-90	0-90246																									
0-25	0-25068	0-58	0-58159	0-91	0-91249																									
0-26	0-26071	0-59	0-59162	0-92	0-92252																									
0-27	0-27074	0-60	0-60164	0-93	0-93255																									
0-28	0-28077	0-61	0-61167	0-94	0-94257																									
0-29	0-29079	0-62	0-62170	0-95	0-95260																									
0-30	0-30082	0-63	0-63173	0-96	0-96263																									
0-31	0-31085	0-64	0-64175	0-97	0-97266																									
0-32	0-32088	0-65	0-65178	0-98	0-98268																									
0-33	0-33090	0-66	0-66181	0-99	0-99271																									

TABLE K.

Shewing the correction to be applied to a Barometer with a Brass Scale, extending from the Cistern to the Top of the Mercurial Column, to reduce the Observation to 32° Fahrenheit.

Temperature Fahrenheit.	OBSERVED HEIGHTS OF THE BAROMETER IN INCHES.											
	28-1	28-2	28-3	28-4	28-5	28-6	28-7	28-8	28-9	28-0	29-1	29-2
50	.054	.064	.054	.055	.055	.055	.055	.055	.056	.056	.056	.056
51	.067	.067	.057	.067	.067	.058	.058	.058	.059	.059	.059	.059
52	.059	.059	.059	.060	.060	.060	.060	.061	.061	.061	.061	.061
53	.062	.062	.062	.062	.062	.063	.063	.063	.063	.064	.064	.064
54	.064	.064	.065	.065	.065	.065	.065	.066	.066	.066	.066	.067
55	.067	.067	.067	.067	.068	.068	.068	.068	.069	.069	.069	.069
56	.069	.069	.070	.070	.070	.070	.071	.071	.071	.071	.072	.072
57	.072	.072	.072	.072	.073	.073	.073	.073	.074	.074	.074	.074
58	.074	.074	.075	.075	.075	.075	.076	.076	.076	.076	.077	.077
59	.077	.077	.077	.077	.078	.078	.078	.078	.079	.079	.079	.080
60	.079	.079	.080	.080	.080	.080	.081	.081	.081	.082	.082	.082
61	.082	.082	.082	.082	.083	.083	.083	.084	.084	.084	.084	.085
62	.084	.084	.085	.085	.085	.086	.086	.086	.086	.087	.087	.087
63	.087	.087	.087	.087	.088	.088	.088	.089	.089	.089	.090	.090
64	.089	.089	.090	.090	.090	.091	.091	.091	.092	.092	.092	.093
65	.092	.092	.092	.093	.093	.093	.093	.094	.094	.094	.095	.095
66	.094	.094	.095	.095	.095	.096	.096	.096	.097	.097	.097	.098
67	.097	.097	.097	.098	.098	.098	.099	.099	.099	.100	.100	.100
68	.099	.099	.100	.100	.100	.101	.101	.101	.102	.102	.103	.103
69	.102	.102	.102	.103	.103	.103	.104	.104	.104	.105	.105	.105
70	.104	.104	.105	.105	.105	.106	.106	.107	.107	.107	.108	.108
71	.106	.107	.107	.108	.108	.108	.109	.109	.110	.110	.110	.111
72	.109	.109	.110	.110	.111	.111	.111	.112	.112	.112	.113	.113
73	.111	.112	.112	.113	.113	.113	.114	.114	.115	.115	.115	.116
74	.114	.114	.115	.115	.116	.116	.116	.117	.117	.118	.118	.118
75	.116	.117	.117	.118	.119	.119	.119	.120	.120	.120	.121	.121
76	.119	.119	.120	.120	.121	.121	.121	.122	.122	.123	.123	.124
77	.121	.122	.122	.123	.123	.124	.124	.124	.125	.125	.126	.126
78	.124	.124	.125	.125	.126	.126	.127	.127	.127	.128	.128	.129
79	.126	.127	.127	.128	.128	.129	.129	.130	.130	.131	.131	.131
80	.129	.129	.130	.130	.131	.131	.132	.132	.133	.133	.133	.134
81	.131	.132	.132	.133	.133	.134	.134	.135	.135	.136	.136	.137
82	.134	.134	.135	.135	.136	.136	.137	.137	.138	.138	.139	.139
83	.136	.137	.137	.138	.138	.139	.139	.140	.140	.141	.141	.142
84	.139	.139	.140	.140	.141	.141	.142	.142	.143	.143	.144	.144
85	.141	.142	.142	.143	.143	.144	.144	.145	.145	.146	.146	.147
86	.144	.144	.145	.145	.146	.146	.147	.147	.148	.148	.149	.149
87	.146	.147	.147	.148	.148	.149	.149	.150	.150	.151	.152	.152
88	.149	.149	.150	.150	.151	.151	.152	.152	.153	.154	.154	.155
89	.151	.152	.152	.153	.153	.154	.154	.155	.156	.156	.157	.157
90	.154	.154	.155	.155	.156	.156	.157	.158	.158	.159	.159	.160
91	.156	.157	.157	.158	.158	.159	.160	.160	.161	.161	.162	.162
92	.159	.159	.160	.160	.161	.162	.162	.163	.163	.164	.164	.165
93	.161	.162	.162	.163	.163	.164	.165	.165	.166	.166	.167	.168
94	.164	.164	.165	.165	.166	.167	.167	.168	.168	.169	.169	.170
95	.166	.167	.167	.168	.169	.169	.170	.170	.171	.171	.172	.173
96	.169	.169	.170	.170	.171	.172	.172	.173	.173	.174	.175	.175
97	.171	.172	.172	.173	.174	.174	.175	.175	.176	.177	.177	.178
98	.174	.174	.175	.175	.176	.177	.177	.178	.179	.179	.180	.180
99	.176	.177	.177	.178	.179	.179	.180	.180	.181	.182	.182	.183
100	.179	.179	.180	.180	.181	.182	.182	.183	.184	.184	.185	.186
101	.181	.182	.182	.183	.184	.184	.185	.186	.186	.187	.187	.188
102	.184	.184	.185	.185	.186	.187	.187	.188	.189	.189	.190	.191
103	.186	.187	.187	.188	.189	.189	.190	.191	.191	.192	.193	.193
104	.188	.189	.190	.190	.191	.192	.192	.193	.194	.194	.195	.196
105	.191	.192	.192	.193	.194	.194	.195	.196	.196	.197	.198	.198
106	.193	.194	.195	.195	.196	.197	.198	.198	.199	.200	.200	.201
107	.196	.197	.197	.198	.199	.199	.200	.201	.201	.202	.203	.204
108	.198	.199	.200	.200	.201	.202	.203	.203	.204	.205	.205	.206
109	.201	.202	.202	.203	.204	.204	.205	.206	.207	.207	.208	.209
110	.203	.204	.205	.205	.206	.207	.208	.208	.209	.210	.211	.211

TABLE K.

Shewing the correction to be applied to a Barometer with a Brass Scale, extending from the Cistern to the Top of the Mercurial Column, to reduce the Observation to 32° Fahrenheit.

Temperature Fahrenheit.	OBSERVED HEIGHTS OF THE BAROMETER IN INCHES.											
	29.3	29.4	29.5	29.6	29.7	29.8	29.9	30.0	30.1	30.2	30.3	30.4
50	.056	.057	.057	.057	.057	.057	.058	.058	.058	.058	.058	.058
51	.059	.059	.059	.060	.060	.060	.060	.060	.061	.061	.061	.061
52	.062	.062	.062	.062	.062	.063	.063	.063	.063	.063	.064	.064
53	.064	.064	.065	.065	.065	.065	.066	.066	.066	.066	.066	.067
54	.067	.067	.067	.067	.068	.068	.068	.068	.069	.069	.069	.069
55	.069	.070	.070	.070	.070	.071	.071	.071	.071	.072	.072	.072
56	.072	.072	.073	.073	.073	.073	.073	.074	.074	.074	.074	.075
57	.075	.075	.075	.075	.076	.076	.076	.076	.077	.077	.077	.077
58	.077	.077	.078	.078	.078	.079	.079	.079	.080	.080	.080	.080
59	.080	.080	.080	.081	.081	.081	.081	.082	.082	.082	.083	.083
60	.082	.083	.083	.083	.084	.084	.084	.084	.085	.085	.085	.086
61	.085	.085	.086	.086	.086	.086	.087	.087	.087	.088	.088	.088
62	.088	.088	.088	.089	.089	.089	.089	.090	.090	.090	.091	.091
63	.090	.091	.091	.091	.091	.092	.092	.092	.093	.093	.093	.094
64	.093	.093	.093	.094	.094	.094	.095	.095	.095	.096	.096	.096
65	.095	.096	.096	.096	.097	.097	.097	.098	.098	.098	.099	.099
66	.098	.098	.099	.099	.099	.100	.100	.100	.101	.101	.101	.102
67	.101	.101	.101	.102	.102	.102	.103	.103	.103	.104	.104	.104
68	.103	.104	.104	.104	.105	.105	.105	.106	.106	.106	.107	.107
69	.106	.106	.107	.107	.107	.108	.108	.108	.109	.109	.109	.110
70	.108	.109	.109	.110	.110	.110	.111	.111	.111	.112	.112	.113
71	.111	.111	.112	.112	.113	.113	.113	.114	.114	.114	.115	.115
72	.114	.114	.114	.115	.115	.116	.116	.116	.117	.117	.118	.118
73	.116	.117	.117	.117	.118	.118	.119	.119	.119	.120	.120	.121
74	.119	.119	.120	.120	.120	.121	.121	.122	.122	.122	.123	.123
75	.121	.122	.122	.123	.123	.124	.124	.124	.125	.125	.126	.126
76	.124	.124	.125	.125	.126	.126	.127	.127	.127	.128	.128	.129
77	.127	.127	.127	.128	.128	.129	.129	.130	.130	.131	.131	.131
78	.129	.130	.130	.131	.131	.131	.132	.132	.133	.133	.134	.134
79	.132	.132	.133	.133	.134	.134	.135	.135	.135	.136	.136	.137
80	.134	.135	.135	.136	.136	.137	.137	.138	.138	.139	.139	.139
81	.137	.137	.138	.138	.139	.139	.140	.140	.141	.141	.142	.142
82	.140	.140	.141	.141	.141	.142	.142	.143	.143	.144	.144	.145
83	.142	.143	.143	.144	.144	.145	.145	.146	.146	.147	.147	.148
84	.145	.145	.146	.146	.147	.147	.148	.148	.149	.149	.150	.150
85	.147	.148	.148	.149	.149	.150	.150	.151	.151	.152	.152	.153
86	.150	.150	.151	.151	.152	.153	.153	.154	.154	.155	.155	.156
87	.153	.153	.154	.154	.155	.155	.156	.156	.157	.157	.158	.158
88	.155	.156	.156	.157	.157	.158	.158	.159	.159	.160	.160	.161
89	.158	.158	.159	.159	.160	.160	.161	.161	.162	.163	.163	.164
90	.160	.161	.161	.162	.163	.163	.164	.164	.165	.165	.166	.166
91	.163	.163	.164	.165	.165	.166	.166	.167	.167	.168	.168	.169
92	.165	.166	.167	.167	.168	.168	.169	.169	.170	.171	.171	.172
93	.168	.169	.169	.170	.170	.171	.172	.172	.173	.173	.174	.174
94	.171	.171	.172	.172	.173	.174	.174	.175	.175	.176	.176	.177
95	.173	.174	.174	.175	.176	.176	.177	.177	.178	.179	.179	.180
96	.176	.176	.177	.178	.178	.179	.179	.180	.181	.181	.182	.182
97	.178	.179	.180	.180	.181	.181	.182	.183	.183	.184	.185	.185
98	.181	.182	.182	.183	.183	.184	.185	.185	.186	.187	.187	.188
99	.184	.184	.185	.185	.186	.187	.187	.188	.189	.189	.190	.190
100	.186	.187	.187	.188	.189	.189	.190	.191	.191	.192	.193	.193
101	.189	.189	.190	.191	.191	.192	.193	.193	.194	.195	.195	.196
102	.191	.192	.193	.193	.194	.195	.195	.196	.197	.197	.198	.199
103	.194	.195	.195	.196	.197	.197	.198	.199	.199	.200	.201	.201
104	.197	.197	.198	.199	.199	.200	.201	.201	.202	.203	.203	.204
105	.199	.200	.200	.201	.202	.202	.203	.204	.205	.205	.206	.207
106	.202	.202	.203	.204	.204	.205	.206	.206	.207	.208	.209	.209
107	.204	.205	.206	.206	.207	.208	.208	.209	.210	.211	.211	.212
108	.207	.208	.208	.209	.210	.210	.211	.212	.212	.213	.214	.215
109	.209	.210	.211	.212	.212	.213	.214	.214	.215	.216	.217	.217
110	.212	.213	.213	.214	.215	.216	.216	.217	.218	.218	.219	.220

TABLE L.
For Converting Acres into Corresponding Beegahs of 80 Haths or 1600 Square Yards.

Acres	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
10	30-250	33-275	36-300	39-325	42-350	45-375	48-400	51-425	54-450	57-475
20	60-500	63-525	66-550	69-575	72-600	75-625	78-650	81-675	84-700	87-725
30	90-750	93-775	96-800	99-825	102-850	105-875	108-900	111-925	114-950	117-975
40	121-000	124-025	127-050	130-075	133-100	136-125	139-150	142-175	145-200	148-225
50	151-250	154-275	157-300	160-325	163-350	166-375	169-400	172-425	175-450	178-475
60	181-500	184-525	187-550	190-575	193-600	196-625	199-650	202-675	205-700	208-725
70	211-750	214-775	217-800	220-825	223-850	226-875	229-900	232-925	235-950	238-975
80	242-000	245-025	248-050	251-075	254-100	257-125	260-150	263-175	266-200	269-225
90	272-250	275-275	278-300	281-325	284-350	287-375	290-400	293-425	296-450	299-475

NOTE.—This Table gives the number of Beegahs corresponding with Acres from 1 to 99, any number above, must be taken out by removing the decimal point, one, two, or as many places to the right, as there are figures in excess of those given in the Table and any decimal of an Acre by removing the point in the same manner to the left.—Thus : the number of Beegahs corresponding with 880 74 Acres is 880 Acres, 2510 75 Beegahs.

6 18-15
0 74 2 23

2531 13 Beegahs.

T A B L E M.

For converting Beegahs of 80 Haths or 1600 Square Yards into Corresponding Acres.

Beegahs.	Acres 0.	Acres 1.	Acres 2.	Acres 3.	Acres 4.	Acres 5.	Acres 6.	Acres 7.	Acres 8.	Acres 9.
10	3-3058	3-3308	3-6616	3-9917	4-3223	4-6529	4-9834	5-3140	5-6446	5-9752
20	6-6116	6-9421	7-2726	7-6034	7-9339	8-2645	8-5950	8-9256	9-2562	9-5868
30	9-9174	10-2479	10-5786	10-9091	11-2397	11-5703	11-9008	12-2314	12-5620	12-8926
40	13-2232	13-5537	13-8843	14-2149	14-5455	14-8761	15-2068	15-5374	15-8679	16-1984
50	16-5290	16-8595	17-1901	17-5207	17-8513	18-1819	18-5124	18-8430	19-1736	19-5042
60	19-8348	20-1653	20-4959	20-8265	21-1571	21-4877	21-8183	22-1488	22-4794	22-8100
70	23-1406	23-4711	23-8017	24-1324	24-4632	24-7938	25-1245	25-4546	25-7852	26-1158
80	26-4464	26-7769	27-1075	27-4381	27-7687	28-0993	28-4298	28-7604	29-0910	29-4216
90	29-7522	30-0827	30-4133	30-7439	31-0745	31-4051	31-7358	32-0663	32-3968	32-7274

NOTE.—This Table gives the number of Acres corresponding with Beegahs from 1 to 99, and is made use of in the same manner as Table L. Thus: the number of Acres corresponding with 2531.13 Beegahs is 2500 Beegahs, 826.95 Acres.

31 " 10.247
 0.13 " 0.043

826.74 Acres.

TABLE O.

Of Square Measure for Bengal Standard Beegah of 14400 Square Feet or 1600 Square Yards.

Beegahs by Beegahs.

(1)

1	2	3	4	5	6	7	8	9	10
1	1	2	3	4	5	6	7	8	9
2	2	4	6	8	10	12	14	16	18
3	3	6	9	12	15	18	21	24	27
4	4	8	12	16	20	24	28	32	36
5	5	10	15	20	25	30	35	40	45
6	6	12	18	24	30	36	42	48	54
7	7	14	21	28	35	42	49	56	63
8	8	16	24	32	40	48	56	64	72
9	9	18	27	36	45	54	63	72	81
10	10	20	30	40	50	60	70	80	90

TABLE OF SQUARE MEASURE.

Sq. Feet.	Gundah.	Chittack.	Cottah.
45	= 20	= 1	= 1 Beegah.
720	= 320	= 16	= 20
14400	= 6000	= 320	= 400
43560	= 18360	= 968	= 6075 = 3.025 = 1 Acre.

Rule for Duodecimals.—Under the terms of the Multiplicand write the corresponding denominations of the Multiplier, so that Beegahs may stand under Beegahs, Cottahs under Cottahs, and Chittacks under Chittacks. Then multiply each term in the Multiplicand, beginning at the lowest, by the Beegahs in the Multiplier, and write the result under its respective term. In the same manner multiply all the terms of the Multiplicand by the Cottahs in the Multipliers, and write the result one place removed to the right hand of those in the Multiplicand. Proceed in like manner with the Chittacks, and the sum of all these products will give the area required.

Rule for Tables.—Take out from each Table the quantity required, placing it under its respective term, (agreeably to the rule given for Duodecimals), for Beegahs, Cottahs and Chittacks, the sum will be the area required.

EXAMPLE.

Required the area of a Field, the breadth being 4 B, 8 C., 9 C., and the length 5 B., 10 C., 6 C. P

B.	C.	C.
4	8	9
5	10	6

Table 1-20

"	2	2	13
"	4	0	4
"	2	0	4
"	0	0	4
"	3	0	1
"	0	0	2
"	0	0	0

NOTE.—In practice it would be unnecessary to carry out the calculation to the extent of Gundahs, unless very great accuracy was required.

Area required, or 24 Beegahs, 8 Cottahs, 12 Chittacks and 137 Gundahs.

XXI.

Beegahs by Cottahs.

(2)

Oot.	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19			
	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.	B.	C.				
1	0	1	0	2	0	3	0	4	0	5	0	6	0	7	0	8	0	9	0	10	0	11	0	12	0	13	0	14	0	15	0	16	0	17	0	18	0	19	0	
2	0	2	0	4	0	6	0	8	0	10	0	12	0	14	0	16	0	18	0	20	0	22	0	24	0	26	0	28	0	30	0	32	0	34	0	36	0	38	0	40
3	0	3	0	6	0	9	0	12	0	15	0	18	0	21	0	24	0	27	0	30	0	33	0	36	0	39	0	42	0	45	0	48	0	51	0	54	0	57	0	60
4	0	4	0	8	0	12	0	16	0	20	0	24	0	28	0	32	0	36	0	40	0	44	0	48	0	52	0	56	0	60	0	64	0	68	0	72	0	76	0	80
5	0	5	0	10	0	15	0	20	0	25	0	30	0	35	0	40	0	45	0	50	0	55	0	60	0	65	0	70	0	75	0	80	0	85	0	90	0	95	0	100
6	0	6	0	12	0	18	0	24	0	30	0	36	0	42	0	48	0	54	0	60	0	66	0	72	0	78	0	84	0	90	0	96	0	102	0	108	0	114	0	120
7	0	7	0	14	0	21	0	28	0	35	0	42	0	49	0	56	0	63	0	70	0	77	0	84	0	91	0	98	0	105	0	112	0	119	0	126	0	133	0	140
8	0	8	0	16	0	24	0	32	0	40	0	48	0	56	0	64	0	72	0	80	0	88	0	96	0	104	0	112	0	120	0	128	0	136	0	144	0	152	0	160
9	0	9	0	18	0	27	0	36	0	45	0	54	0	63	0	72	0	81	0	90	0	99	0	108	0	117	0	126	0	135	0	144	0	153	0	162	0	171	0	180
10	0	10	0	20	0	30	0	40	0	50	0	60	0	70	0	80	0	90	0	100	0	110	0	120	0	130	0	140	0	150	0	160	0	170	0	180	0	190	0	200

TABLE O.—(Continued.)
Beegahs by Chittacks.

Chittacks.	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19						
	Beeg.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.					
1	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10	0 11	0 12	0 13	0 14	0 15	0 16	0 17	0 18	0 19	0 20	0 21	0 22	0 23	0 24	0 25	0 26	0 27	0 28	0 29	0 30	0 31	0 32	0 33	0 34	0 35	0 36	0 37	0 38	0 39	0 40			
2	0 2	0 4	0 6	0 8	0 10	0 12	0 14	0 16	0 18	0 20	0 22	0 24	0 26	0 28	0 30	0 32	0 34	0 36	0 38	0 40	0 42	0 44	0 46	0 48	0 50	0 52	0 54	0 56	0 58	0 60	0 62	0 64	0 66	0 68	0 70	0 72	0 74	0 76	0 78	0 80			
3	0 3	0 6	0 9	0 12	0 15	0 18	0 21	0 24	0 27	0 30	0 33	0 36	0 39	0 42	0 45	0 48	0 51	0 54	0 57	0 60	0 63	0 66	0 69	0 72	0 75	0 78	0 81	0 84	0 87	0 90	0 93	0 96	0 99	1 02	1 05	1 08	1 11	1 14	1 17	1 20			
4	0 4	0 8	0 12	0 16	0 20	0 24	0 28	0 32	0 36	0 40	0 44	0 48	0 52	0 56	0 60	0 64	0 68	0 72	0 76	0 80	0 84	0 88	0 92	0 96	1 00	1 04	1 08	1 12	1 16	1 20	1 24	1 28	1 32	1 36	1 40	1 44	1 48	1 52	1 56	1 60	1 64		
5	0 5	0 10	0 15	0 20	0 25	0 30	0 35	0 40	0 45	0 50	0 55	0 60	0 65	0 70	0 75	0 80	0 85	0 90	0 95	1 00	1 05	1 10	1 15	1 20	1 25	1 30	1 35	1 40	1 45	1 50	1 55	1 60	1 65	1 70	1 75	1 80	1 85	1 90	1 95	2 00	2 05		
6	0 6	0 12	0 18	0 24	0 30	0 36	0 42	0 48	0 54	0 60	0 66	0 72	0 78	0 84	0 90	0 96	1 02	1 08	1 14	1 20	1 26	1 32	1 38	1 44	1 50	1 56	1 62	1 68	1 74	1 80	1 86	1 92	1 98	2 04	2 10	2 16	2 22	2 28	2 34	2 40	2 46		
7	0 7	0 14	0 21	0 28	0 35	0 42	0 49	0 56	0 63	0 70	0 77	0 84	0 91	0 98	1 05	1 12	1 19	1 26	1 33	1 40	1 47	1 54	1 61	1 68	1 75	1 82	1 89	1 96	2 03	2 10	2 17	2 24	2 31	2 38	2 45	2 52	2 59	3 06	3 13	3 20	3 27		
8	0 8	0 16	0 24	0 32	0 40	0 48	0 56	0 64	0 72	0 80	0 88	0 96	1 04	1 12	1 20	1 28	1 36	1 44	1 52	1 60	1 68	1 76	1 84	1 92	2 00	2 08	2 16	2 24	2 32	2 40	2 48	2 56	3 04	3 12	3 20	3 28	3 36	3 44	3 52	4 00	4 08	4 16	
9	0 9	0 18	0 27	0 36	0 45	0 54	0 63	0 72	0 81	0 90	0 99	1 08	1 17	1 26	1 35	1 44	1 53	1 62	1 71	1 80	1 89	1 98	2 07	2 16	2 25	2 34	2 43	2 52	3 01	3 10	3 19	3 28	3 37	3 46	3 55	4 04	4 13	4 22	4 31	4 40	4 49	4 58	
10	0 10	0 20	0 30	0 40	0 50	0 60	0 70	0 80	0 90	1 00	1 10	1 20	1 30	1 40	1 50	1 60	1 70	1 80	1 90	2 00	2 10	2 20	2 30	2 40	2 50	3 00	3 10	3 20	3 30	3 40	3 50	4 00	4 10	4 20	4 30	4 40	4 50	5 00	5 10	5 20	5 30	5 40	5 50

Cottahs by Cottahs.

(4)

Cott.	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19				
	Col.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.	C. C.			
1	0 0	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10	0 11	0 12	0 13	0 14	0 15	0 16	0 17	0 18	0 19	0 20	0 21	0 22	0 23	0 24	0 25	0 26	0 27	0 28	0 29	0 30	0 31	0 32	0 33	0 34	0 35	0 36	0 37	0 38		
2	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10	0 11	0 12	0 13	0 14	0 15	0 16	0 17	0 18	0 19	0 20	0 21	0 22	0 23	0 24	0 25	0 26	0 27	0 28	0 29	0 30	0 31	0 32	0 33	0 34	0 35	0 36	0 37	0 38	0 39	0 40	
3	0 2	0 4	0 6	0 8	0 10	0 12	0 14	0 16	0 18	0 20	0 22	0 24	0 26	0 28	0 30	0 32	0 34	0 36	0 38	0 40	0 42	0 44	0 46	0 48	0 50	0 52	0 54	0 56	0 58	0 60	0 62	0 64	0 66	0 68	0 70	0 72	0 74	0 76	0 78	0 80	
4	0 3	0 6	0 9	0 12	0 15	0 18	0 21	0 24	0 27	0 30	0 33	0 36	0 39	0 42	0 45	0 48	0 51	0 54	0 57	0 60	0 63	0 66	0 69	0 72	0 75	0 78	0 81	0 84	0 87	0 90	0 93	0 96	0 99	1 02	1 05	1 08	1 11	1 14	1 17	1 20	
5	0 4	0 8	0 12	0 16	0 20	0 24	0 28	0 32	0 36	0 40	0 44	0 48	0 52	0 56	0 60	0 64	0 68	0 72	0 76	0 80	0 84	0 88	0 92	0 96	1 00	1 04	1 08	1 12	1 16	1 20	1 24	1 28	1 32	1 36	1 40	1 44	1 48	1 52	1 56	1 60	1 64
6	0 5	0 10	0 15	0 20	0 25	0 30	0 35	0 40	0 45	0 50	0 55	0 60	0 65	0 70	0 75	0 80	0 85	0 90	0 95	1 00	1 05	1 10	1 15	1 20	1 25	1 30	1 35	1 40	1 45	1 50	1 55	1 60	1 65	1 70	1 75	1 80	1 85	1 90	1 95	2 00	
7	0 6	0 12	0 18	0 24	0 30	0 36	0 42	0 48	0 54	0 60	0 66	0 72	0 78	0 84	0 90	0 96	1 02	1 08	1 14	1 20	1 26	1 32	1 38	1 44	1 50	1 56	1 62	1 68	1 74	1 80	1 86	1 92	1 98	2 04	2 10	2 16	2 22	2 28	2 34	2 40	2 46
8	0 7	0 14	0 21	0 28	0 35	0 42	0 49	0 56	0 63	0 70	0 77	0 84	0 91	0 98	1 05	1 12	1 19	1 26	1 33	1 40	1 47	1 54	1 61	1 68	1 75	1 82	1 89	1 96	2 03	2 10	2 17	2 24	2 31	2 38	2 45	2 52	2 59	3 06	3 13	3 20	3 27
9	0 8	0 16	0 24	0 32	0 40	0 48	0 56	0 64	0 72	0 80	0 88	0 96	1 04	1 12	1 20	1 28	1 36	1 44	1 52	1 60	1 68	1 76	1 84	1 92	2 00	2 08	2 16	2 24	2 32	2 40	2 48	2 56	3 04	3 12	3 20	3 28	3 36	3 44	3 52	4 00	4 08
10	0 9	0 18	0 27	0 36	0 45	0 54	0 63	0 72	0 81	0 90	0 99	1 08	1 17	1 26	1 35	1 44	1 53	1 62	1 71	1 80	1 89	1 98	2 07	2 16	2 25	2 34	2 43	2 52	3 01	3 10	3 19	3 28	3 37	3 46	3 55	4 04	4 13	4 22	4 31	4 40	4 49

TABLE O.—(Continued.)
Cottahs by Chittacks.

Chittacks.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cot.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.	Cks. G.
1	0 1	0 2	0 3	0 4	0 5	0 6	0 7	0 8	0 9	0 10	0 11	0 12	0 13	0 14	0 15
2	0 3	0 4	0 6	0 8	0 10	0 12	0 14	0 16	0 18	1 0	1 2	1 4	1 6	1 8	1 10
3	0 4	0 6	0 9	0 12	0 15	0 18	1 1	1 4	1 7	1 10	1 13	1 16	1 19	2 2	2 5
4	0 5	0 8	0 12	0 16	1 0	1 4	1 8	1 12	1 16	2 0	2 4	2 8	3 2	3 6	3 0
5	0 6	0 10	0 15	1 0	1 5	1 10	1 15	2 0	2 5	3 0	3 5	3 0	3 5	3 10	3 15
6	0 6	0 12	0 18	1 4	1 10	1 16	2 2	2 8	3 4	3 10	3 6	4 2	4 8	4 4	4 10
7	0 7	0 14	1 1	1 8	1 15	2 2	2 9	3 6	4 3	5 0	3 7	4 4	5 1	4 18	5 5
8	0 9	0 16	1 4	1 12	2 0	2 8	3 6	4 4	5 2	6 0	4 8	5 6	6 4	5 12	6 0
9	0 9	0 18	1 7	1 16	2 5	3 4	4 3	5 2	6 1	7 0	5 9	6 8	7 7	6 6	7 5
10	0 10	1 0	1 10	2 0	3 0	4 0	5 0	6 0	7 0	8 0	9 0	10 0	11 0	12 0	13 0
11	0 11	1 4	1 13	2 4	3 5	4 6	5 7	6 8	7 9	8 10	9 11	10 12	11 13	12 14	13 15
12	0 12	1 4	1 16	2 8	3 0	3 12	4 4	4 16	5 8	6 0	6 12	7 4	7 16	8 8	9 0
13	0 13	1 6	1 19	3 12	3 5	3 18	4 11	5 4	6 7	7 0	8 3	9 6	10 9	11 12	12 15
14	0 14	1 10	2 2	3 0	3 15	4 4	5 3	6 2	7 1	8 0	8 9	9 8	10 7	11 6	12 5
15	0 15	1 12	2 11	3 8	4 4	5 2	6 0	6 8	7 6	8 4	9 2	10 0	10 8	11 6	12 4
16	0 16	1 14	2 14	3 8	4 5	5 3	6 1	6 16	7 4	8 10	8 7	9 4	10 1	10 8	11 5
17	0 17	1 14	2 14	3 12	4 10	5 8	6 6	7 4	8 2	9 0	9 7	10 4	11 1	11 8	12 5
18	0 18	1 16	2 14	3 12	4 10	5 8	6 6	7 4	8 2	9 0	9 7	10 4	11 1	11 8	12 5
19	0 19	1 18	2 17	3 16	4 15	5 14	6 13	7 12	8 11	9 10	10 9	11 8	12 7	13 6	14 5

Chittacks by Cottahs.

Chittacks.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Chit.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.	G. Dec.
1	0 06	0 13	0 19	0 25	0 31	0 37	0 44	0 50	0 56	0 62	0 68	0 75	0 81	0 87	0 94
2	0 12	0 25	0 37	0 50	0 62	0 75	0 87	1 00	1 12	1 24	1 36	1 50	1 62	1 75	1 87
3	0 19	0 37	0 56	0 75	0 94	1 12	1 31	1 50	1 68	1 88	2 07	2 25	2 44	2 62	2 81
4	0 25	0 50	0 75	1 00	1 25	1 50	1 75	2 00	2 25	2 50	2 75	3 00	3 25	3 50	3 75
5	0 31	0 63	0 94	1 25	1 56	1 87	2 18	2 50	2 81	3 12	3 43	3 75	4 06	4 37	4 68
6	0 37	0 75	1 12	1 50	1 87	2 25	2 63	3 00	3 37	3 74	4 11	4 50	4 87	5 25	5 63
7	0 44	0 87	1 31	1 75	2 19	2 63	3 06	3 50	3 94	4 38	4 82	5 25	5 68	6 13	6 58
8	0 50	1 00	1 50	2 00	2 50	3 00	3 50	4 00	4 50	5 00	5 50	6 00	6 50	7 00	7 50
9	0 56	1 12	1 69	2 25	2 81	3 37	3 93	4 50	5 08	5 62	6 18	6 75	7 31	7 87	8 44
10	0 62	1 25	1 89	2 50	3 12	3 75	4 37	5 00	5 63	6 25	6 88	7 50	8 12	8 74	9 37
11	0 68	1 37	2 06	2 75	3 44	4 13	4 81	5 50	6 19	6 88	7 57	8 25	8 93	9 61	10 31
12	0 75	1 60	2 26	3 00	3 75	4 50	5 25	6 00	6 75	7 50	8 25	9 00	9 75	10 50	11 25
13	0 81	1 63	2 44	3 25	4 06	4 87	5 68	6 50	7 31	8 12	8 93	9 75	10 56	11 37	12 19
14	0 87	1 75	2 63	3 50	4 37	5 25	6 12	7 00	7 87	8 74	9 61	10 50	11 37	12 24	13 13
15	0 94	1 87	2 81	3 75	4 68	5 63	6 56	7 50	8 44	9 37	10 31	11 26	12 19	13 12	14 06

T A B L E P.
For Converting Acres into Beegahs of 3025 Square Yards.

ACRES.	ACRES INTO BEEGAHS.									
	0	1	2	3	4	5	6	7	8	9
	Beeghs. B.	Beeghs. B.	Beeghs. B.	Beeghs. B.	Beeghs. B.	Beeghs. B.	Beeghs. B.	Beeghs. B.	Beeghs. B.	Beeghs. B.
0 to 9	0	1	2	3	4	5	6	7	8	9
10 "	16	17	12	4	16	8	25	12	12	16
20 "	32	33	12	8	32	8	41	12	23	30
30 "	48	49	12	12	48	8	57	12	44	46
40 "	64	65	12	16	64	8	73	12	60	62
50 "	80	81	12	20	80	8	89	12	76	78
60 "	96	97	12	24	96	8	105	12	92	94
70 "	112	113	12	28	112	8	121	12	108	110
80 "	128	129	12	32	128	8	137	12	124	126
90 "	144	145	12	36	144	8	153	12	140	142
0 "	0	160	320	480	640	800	960	1120	1280	1440
1000 "	1800	1760	1820	2080	2240	2400	2560	2720	2880	3040
2000 "	3600	3360	3520	3680	3840	4000	4160	4320	4480	4640
3000 "	5400	4960	5120	5280	5440	5600	5760	5920	6080	6240
4000 "	7200	6560	6720	6880	7040	7200	7360	7520	7680	7840
5000 "	9000	8160	8320	8480	8640	8800	8960	9120	9280	9440
6000 "	10800	9760	9920	10080	10240	10400	10560	10720	10880	11040
7000 "	11200	11360	11520	11680	11840	12000	12160	12320	12480	12640

POLES INTO BEEGAHS.

POLES.	POLES INTO BEEGAHS.								
	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.
0 to 9	0	0	0	0	0	0	0	0	0
10 "	0	0	4	0	0	0	1	4	0
20 "	0	2	4	0	2	16	0	3	4
30 "	0	4	4	0	4	16	0	5	4
40 "	0	6	4	0	6	16	0	7	4
50 "	0	8	0	0	8	0	0	8	0
60 "	0	8	0	0	8	0	0	8	0
70 "	0	8	0	0	8	0	0	8	0
80 "	0	8	0	0	8	0	0	8	0
90 "	0	8	0	0	8	0	0	8	0
1000 "	0	16	0	0	16	0	0	16	0
2000 "	0	16	0	0	16	0	0	16	0
3000 "	0	16	0	0	16	0	0	16	0
4000 "	0	16	0	0	16	0	0	16	0
5000 "	0	16	0	0	16	0	0	16	0
6000 "	0	16	0	0	16	0	0	16	0
7000 "	0	16	0	0	16	0	0	16	0
8000 "	0	16	0	0	16	0	0	16	0
9000 "	0	16	0	0	16	0	0	16	0

ROODS INTO BEEGAHS.

ROODS.	ROODS INTO BEEGAHS.								
	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.	B. B. B.
0 to 3	0	0	0	0	0	0	0	0	0
4	1	4	0	0	0	0	0	0	0
5	1	4	0	0	0	0	0	0	0
6	1	4	0	0	0	0	0	0	0
7	1	4	0	0	0	0	0	0	0
8	1	4	0	0	0	0	0	0	0
9	1	4	0	0	0	0	0	0	0

20 Biswansees = 1 Bihwah
20 " = 1 Beegah = 3025 Square Yards.

T A B L E R.
For Converting Beegahs of 3025 Square Yards into Acres.

BEEGAH.		BEEGAHS INTO ACRES.															
		0	1	2	3	4	5	6	7	8	9						
Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.
0 to 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 "	6	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
20 "	12	3	6	9	12	15	18	21	24	27	30	33	36	39	42	45	48
30 "	18	9	13	20	27	34	41	48	55	62	69	76	83	90	97	104	111
40 "	24	13	20	27	34	41	48	55	62	69	76	83	90	97	104	111	118
50 "	30	19	26	33	40	47	54	61	68	75	82	89	96	103	110	117	124
60 "	36	25	32	39	46	53	60	67	74	81	88	95	102	109	116	123	130
70 "	42	31	38	45	52	59	66	73	80	87	94	101	108	115	122	129	136
80 "	48	37	44	51	58	65	72	79	86	93	100	107	114	121	128	135	142
90 "	54	43	50	57	64	71	78	85	92	99	106	113	120	127	134	141	148
0	56	49	56	63	70	77	84	91	98	105	112	119	126	133	140	147	154
1000 "	62	69	76	83	90	97	104	111	118	125	132	139	146	153	160	167	174
2000 "	124	131	138	145	152	159	166	173	180	187	194	201	208	215	222	229	236
3000 "	186	193	200	207	214	221	228	235	242	249	256	263	270	277	284	291	298
4000 "	248	255	262	269	276	283	290	297	304	311	318	325	332	339	346	353	360
5000 "	310	317	324	331	338	345	352	359	366	373	380	387	394	401	408	415	422
6000 "	372	379	386	393	400	407	414	421	428	435	442	449	456	463	470	477	484
7000 "	434	441	448	455	462	469	476	483	490	497	504	511	518	525	532	539	546

BISWAS.		BISWAS INTO BODDS AND POLES.															
		0	1	2	3	4	5	6	7	8	9						
Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.
0 to 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 "	0	1	10	0	1	15	0	1	20	0	1	25	0	1	30	0	1
20 "	0	2	20	0	2	40	0	2	40	0	2	50	0	2	60	0	2
30 "	0	3	30	0	3	60	0	3	60	0	3	70	0	3	80	0	3
40 "	0	4	40	0	4	80	0	4	80	0	4	90	0	4	100	0	4
50 "	0	5	50	0	5	100	0	5	100	0	5	110	0	5	120	0	5
60 "	0	6	60	0	6	120	0	6	120	0	6	130	0	6	140	0	6
70 "	0	7	70	0	7	140	0	7	140	0	7	150	0	7	160	0	7
80 "	0	8	80	0	8	160	0	8	160	0	8	170	0	8	180	0	8
90 "	0	9	90	0	9	180	0	9	180	0	9	190	0	9	200	0	9
1000 "	0	10	1000	0	10	2000	0	10	2000	0	10	2100	0	10	2200	0	10
2000 "	0	20	2000	0	20	4000	0	20	4000	0	20	4100	0	20	4200	0	20
3000 "	0	30	3000	0	30	6000	0	30	6000	0	30	6100	0	30	6200	0	30
4000 "	0	40	4000	0	40	8000	0	40	8000	0	40	8100	0	40	8200	0	40
5000 "	0	50	5000	0	50	10000	0	50	10000	0	50	10100	0	50	10200	0	50
6000 "	0	60	6000	0	60	12000	0	60	12000	0	60	12100	0	60	12200	0	60
7000 "	0	70	7000	0	70	14000	0	70	14000	0	70	14100	0	70	14200	0	70

BISWAS.		BISWANSEES INTO POLES.															
		0	1	2	3	4	5	6	7	8	9						
Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.	Acres.	S.
0 to 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10 "	0	0	2 1/2	0	0	5	0	0	7 1/2	0	0	10	0	0	12 1/2	0	0
20 "	0	0	5	0	0	10	0	0	15	0	0	20	0	0	25	0	0
30 "	0	0	7 1/2	0	0	15	0	0	22 1/2	0	0	30	0	0	37 1/2	0	0
40 "	0	0	10	0	0	20	0	0	30	0	0	40	0	0	50	0	0
50 "	0	0	12 1/2	0	0	25	0	0	37 1/2	0	0	50	0	0	62 1/2	0	0
60 "	0	0	15	0	0	30	0	0	45	0	0	60	0	0	75	0	0
70 "	0	0	17 1/2	0	0	35	0	0	52 1/2	0	0	70	0	0	87 1/2	0	0
80 "	0	0	20	0	0	40	0	0	60	0	0	80	0	0	100	0	0
90 "	0	0	22 1/2	0	0	45	0	0	67 1/2	0	0	90	0	0	112 1/2	0	0
1000 "	0	0	25	0	0	50	0	0	75	0	0	100	0	0	125	0	0
2000 "	0	0	50	0	0	100	0	0	150	0	0	200	0	0	250	0	0
3000 "	0	0	75	0	0	150	0	0	225	0	0	300	0	0	375	0	0
4000 "	0	0	100	0	0	200	0	0	300	0	0	400	0	0	500	0	0
5000 "	0	0	125	0	0	250	0	0	375	0	0	500	0	0	625	0	0
6000 "	0	0	150	0	0	300	0	0	450	0	0	600	0	0	750	0	0
7000 "	0	0	175	0	0	350	0	0	525	0	0	700	0	0	875	0	0
8000 "	0	0	200	0	0	400	0	0	600	0	0	800	0	0	1000	0	0
9000 "	0	0	225	0	0	450	0	0	675	0	0	900	0	0	1125	0	0

EXPLANATION AND USE OF THE TABLES.

TABLE A.

For Correcting Gunter's Chains of 100 Links.

In the use of chains, they are found to stretch and unless this quantity is most carefully observed daily by comparison with a standard, all the measurements made will be erroneous and *in defect* in proportion as the chain is too long. This Table, therefore, gives the equivalent in links *to be added* for every inch from one to eleven.

Suppose a chain to have stretched 4 inches;—then for every 10 chains measured, in the column of links opposite 10 and under the heading of 4 inches, will be found 5·051 the number of links to be added, to bring the chains to their proper standard length,—and *vice versâ* for chains too short the same quantity will be *deducted*.

TABLE B.

For reducing Chains to the Decimal parts of a mile.

This Table is useful in the protraction of the co-ordinate distances for general maps on the Geographical scale. For plotting the latitude and departure points from the first station in the series as given in the main Circuit Traverse, the distances require to be divided by 80 for the convenience of scale. By the Table this is avoided and the chance of error, by frequent small divisions, obviated. Thus :

To obtain the value of 345 chains in miles and decimals, look for the even tens and hundreds (340) in the top lines of the Table, and for the odd chains (5) in the left hand column, at the intersection of these two columns will be found 4·3125 the number of miles sought.

TABLE C.

Showing the length of a degree, minute and second of Latitude and Longitude, for every degree of the Quadrant, the compression of the earth being assumed $\frac{1}{287}$.

This Table, (extracted from Boileau's Traverse Tables) is calculated by the Formulæ xliiii, page 116, of Mr. F. Baily's Astronomical Tables and Formulæ; the compression of the earth at the poles being assumed $\frac{1}{287}$, and the mean degree of latitude taken at 364547 feet. The first ten degrees of latitude and

longitude, and afterwards every fifth degree, were computed by the Formulae, the intermediate degrees being filled in by interpolation, by differences carried out as far as such could be done. The degrees of latitude are calculated for the latitudes of their middle points : for instance, the degree in the Table on a line with the number 27, in the first column, is that degree which extends from latitude $26^{\circ} 30'$ to latitude $27^{\circ} 30'$, and in like manner of the rest. The degrees of longitude are computed for the parallels of latitude expressed by the numbers in the same line in the column designated "distance from the equator."

The use of this Table is to convert the Tabular traverses expressed in units of linear measure into their equivalent values of latitude and longitude *in arc*: *i. e.* in degrees, minutes, etc. for that part of the earth's surface to which the traverses belong. For a further description of the use of this Table, see pages 362, 363, etc.

TABLE D.

*For converting Chains and Links into Feet and Decimals
of Feet.*

It frequently happens that measurements made in one denomination require to be converted into their equivalents of another denomination, for instance, route surveys are generally measured with instruments registering yards or feet ; and circumstances may occur, and do frequently happen, where instruments cannot be readily procured, which induce the necessity of making all measurements of every kind in one or other of the above denominations. Land surveys are, however, generally made in Gunter's measure or in links, the 1000th part of a furlong ; and this is the most convenient of all measures for determining the acreage of any extent of surface ; but for geographical purposes the standard unit being the English foot, those measurements are most convenient which are made in this denomination, the length of degrees of latitude and longitude being most frequently expressed in tables in feet also. The arrangement of this table (taken from Boileau's Traverse Tables) requires no explanation.

There being two significant figures in the number of chains, the first denoting tens, the second units, the equivalents must be taken out for each separately. Enter the column of chains corresponding to the significant figures in the first part of the table, where it is an exact decimal multiple of that number, or in the first or second part of the table, according as the number of links is more or less than 50. When the whole distance is less than 10 chains, the first part of the equivalent value is found in the same column under the number of chains and in a line with the number of links in the column so designated ; the last part of the equivalent is found in the column headed deci-

d

imals of feet, of which there is one for each part of the table. The decimal parts are taken out as whole numbers, removing the decimal point in the equivalent number as many places as it is removed in the original. Given the length of a line in a survey 47,25·6 links required its equivalent in feet and decimals.

Ch. ...	Lks.	Ft. ...	Dec.
40 ...	.....	2640 ...	
7 ...	25	478 ...	·50
	·6 .....	... ..	·396
47	25·6	3118	·896 feet.

TABLE E.
Atmospherical Refractions.

This Table from the Nautical Almanac of 1826, is computed upon principles explained by DR. YOUNG in the Philosophical Transactions for 1819 ; and it appears to agree more perfectly with the latest observations than any other table that has been published. The formula employed is

$$\begin{aligned}
 \cdot 0002825 = v \frac{r}{s} + (2\cdot47 + \cdot 5 v^2) \frac{r^3}{s^3} + 3600 v \frac{r^3}{s^3} + 3600 (1\cdot235 \\
 + \cdot 25 v^2) \frac{r^4}{s^4} ; r \text{ being the fraction, } v \text{ the sine of the altitude, and } s \text{ the} \\
 \text{cosine.}
 \end{aligned}$$

The apparent altitude being found in the first column, the second shows the refraction when the barometer stands at 30 inches, which is its mean height on the level of the sea, and the thermometer at 50° of Fahrenheit. The third column contains the difference to be subtracted or added for every minute of altitude, reckoned from the nearest number in the first column. The fourth shows the number of seconds to be added for every inch that the height of the barometer exceeds 30, or to be subtracted for each inch that it wants of 30 : and the last contains the number of seconds to be subtracted for each degree that the thermometer stands above 50°, or to be added for each degree that its height wants of 50°.

If great accuracy be required, we must also deduct from the observed height of the barometer ·003 i. for each degree that the thermometer near it is above 50°, and add an equal quantity for an equal depression. In fact, however, the table, as it now stands, is found to require the temperature to be estimated from the height of the thermometer within ; and if we employed the height of the thermometer without, which would be more consistent with the theory it would probably be necessary to suppose the standard temperature of the table 48° only, instead of 50°.

EXAMPLES.

1. At 7°. 18'. 13" Bar. 29° 87 Ther. 66°, the Refr. is 0'. 52", 26, from 22 obs. of Bradley.
 2. At 19°. 18'. 19" Bar. 30° 045 Ther. 34°, the Refr. is 2'. 51", 5, from 3 obs. of Bradley.
 3. At 13°. 43'. Bar. 29° 85 Ther. 45°, the Refr. is 3'. 55", 85, from 156 obs. of Mr. Pond.

1. Alt. 7°. 20' R. 7'. 8"	Diff. Alt.	" ,9	B. 14",3	Th. ",93
+ 1,62	1'. 47" = 1'. 8	— .13		— 16
7. 9,63	+ 1,62	1,86		14,88
16,74				1,96
6. 52,88				16,74
6. 52,26				

Error..... 0,62

2. Alt. 19°. R. 2'. 47",7	Diff. Alt.	" ,16	B. 5",61	Th. ",34
— 2,93	18'. 19" =	18-3	+ .045	+ 16
2. 44,77	— 2,93	,352		5,44
,25				
5,44				

Error..... 1", 0 2. 50,46

3. Alt. 13. 40' R. 3'. 55",5	Diff. Alt.	" ,29	B. 7",89	Th. ",482
+ ,36	3	.15		5
3. 55,86	— ,87	— 1,18		+ 2,41
3. 55,85		,87		2,05
Error..... ,01			2,05	+ ,36

TABLE F.

Parallax of the Sun.

This table contains the Parallax of the Sun at different degrees of altitude above the horizon and for different months of the year. To find the Parallax for 44 degrees of altitude for the month of April, look in the column of altitude for 44° and on a line with it, and under the column containing the month will be found the parallax, viz. 6".33 always *additive* to the altitude. (From Bagay's Tables.)

TABLE G.

For reversing Angles.

Errors will often occur in reversing the inward or outward angles of a circuit survey. By this table the complement of the angle, or what it wants of 360° can be obtained without the necessity of subtraction. The two upper lines of the table contain the *minutes*, as well as *seconds*, and the remaining columns the *degrees* from 0 to 179 in the left hand divisions, and from 180 to 359 in the right hand divisions of the columns.

To obtain the complement of an angle subtending 348° 14' under 14 in the line of minutes is 46, and in the left division on a line with 348 in the column of degrees is 11. The complement of the angle is therefore 11° 46'.

It seldom happens that observations are taken to full degrees, but in cases where there are no minutes, it will be necessary to add 1° to the number taken from the table. Thus : The complement of an angle subtending 115° will be 244° by the table, to which add 1° will give 245° the complement required.

TABLE H.

Comparative scale of Fahrenheit's, Reaumur's and the Centigrade Thermometers, (from Boileau's Tables) for determining the altitude of mountains.

Equivalents to Fahrenheit's Thermometer in Reaumur's and the Centigrade Scales.

The Temperatures of the Freezing and Boiling points by the several Thermometers, are as follows :

By Fahrenheit's scale,	Freezing point,	32°	Boiling point,	212°
„ Reaumur's ditto	„	0	„	80
„ Centigrade ditto	„	0	„	100

Let x° denote any degree in Fahrenheit's scale ; its value in the other denominations will be expressed by the following Equations :

$$x^\circ \text{ Fahrenheit,} = (x^\circ - 32) \times \frac{4}{9} \dots\dots \text{Reaumur.}$$

$$x^\circ \text{ Fahrenheit,} = (x^\circ - 32) \times \frac{5}{9} \dots\dots \text{Centigrade.}$$

by which Formulæ this Table has been computed.

When the number given is a whole degree Faht. the Equivalent in Degrees of Reaumur and the Centigrade scale is found in the proper column, and in the same horizontal line with the given degree Faht. ; but when the given number contains the decimal of a degree, the Equivalent for the part must be found by proportion.

Example. Required the degree of the Centigrade Thermometer corresponding to 206°·3 Faht.

206°	Faht.,	.....	=	96°·67	Centigrade.
·3	„	=	·55 + $\frac{3}{10}$	=	·16
<hr/>				<hr/>	
206°·3	Faht.		=	96°·83	Centigrade.

The number ·55 is the difference between the equivalents in Centigrade degrees, to 206° and 207° Faht.

In taking out the differences from the columns of equivalents for fractions of degrees Faht. between 32° and 0° the given degree Faht. and the one next less must be employed, as the corresponding value of Reaumur's and the Centigrade scales increase negatively below 32° Faht.

TABLES I AND J.

For converting intervals of sidereal time into equivalent intervals of mean solar time and vice versa.

The tables of time equivalents are useful for converting mean solar into sidereal time and sidereal into mean time agreeably to the example annexed to each table. They will serve, also for tables of acceleration and retardation by taking the difference between each argument and its equivalent. Thus in table J, the *excess* of the sidereal time equivalents above the arguments of mean time shew *acceleration* of sidereal or mean solar intervals; and in table I the *defect* of the mean time equivalents as compared with the arguments of sidereal time, indicate the retardation of mean on sidereal intervals.

These tables, with the above explanation, are given from the Nautical Almanac.

TABLE K.

Showing the correction to be applied to a Barometer with a brass scale, extending from the cistern to the top of the mercurial column, to reduce the observation to 32° Fahrenheit.

The observed height of a Barometer taken at different temperatures before they can be compared with each other, will require reduction to one common temperature. The reduction consists of two parts, one part being due to the dilation of the mercury and the other to that of the brass scale attached to the Barometer; both these corrections are embodied in the following formula:

$$C = B \cdot \frac{(t - 32^\circ) n - (t - 62^\circ) b}{1 + (t - 32^\circ) m}$$

C = Sum of the two corrections.

B = Observed height of the Barometer.

t = { Observed temperature of the Mercury and of the brass scale
which are assumed to be equal.

m = .000100 expansion of Mercury for 1° of Fahrenheit.

b = .0000106 ditto of brass ditto ditto.

32° Standard temperature of Mercury.

62° Ditto, ditto of brass.

By the aid of this formula this Table has been computed which, as it is specially intended for the reduction of the Meteorological Observations taken in the Surveyor General's Office and used for the Printed Monthly Register, is limited to the range of the atmospherical pressure and temperature, which occur in Calcutta; the former extending from inches 28·1 to 30·4, and the latter from 50° to 100° Fahrenheit. More general tables on the subject will be found in the Admiralty Manual of Scientific Enquiry, p. 319. The Corps Papers of the Royal Engineers, and Boileau's Tables 1849.

The arrangement and use of this Table will be best understood from the following example :

Suppose it is required to compute the correction for Barometer 29·780 inches and Thermometer 83° ·3.

The Tabular number for 29·8 inches and 83° Fahrenheit, ...	·145
Alteration for 0·3 Fahrenheit deduced by the common rule } of proportion,	} ·001
<hr style="border: 0; border-top: 1px solid black;"/>	
Required correction,.....	·146
Observed height of the Barometer,	29·780
<hr style="border: 0; border-top: 1px solid black;"/>	
Height reduced to 32° Fahrenheit,.....	29·634
<hr style="border: 0; border-top: 1px solid black;"/>	

It will be remembered that the Tabular correction is always *negative*.

TABLES L, M AND N.

For converting acres into beegahs of 1,600 square yards and vice versa, also for converting the decimal part of an acre or Bengal beegah, into its corresponding value of Roods and Poles, or Cottahs and Chitacks.

The explanation of these tables is given at the foot of each table with examples.

TABLE O.

Table of square Measure.

This table will be found useful in the khusrah measurements, for checking the multiplications of the sides of fields to obtain the contents. The mode of using it together with an example, is given at the head of the table.

TABLES P AND R.

For converting acres into Beegahs of 3,025 square yards and vice versa.

These tables are calculated in the same manner as tables L, M, and N, and are made use of in a similar manner.

MEMORANDUM ON THE MUSEUM OF ECONOMIC GEOLOGY
OF INDIA.

The objects of the Museum of Economic Geology of India, which has been established by Government at Calcutta, under orders from the Hon'ble the Court of Directors, in conjunction with the Asiatic Society and at its Rooms, are the following:—They are, as scientific men will perceive, generally those of Economic Geologists in all countries, but there are some peculiarities connected with India, and the situations of Europeans in it, which will oblige us to go into a little detail, to explain to those who may not already take an interest in these matters, our wants, our wishes, and our hopes of the advantages which may accrue to the community from this new establishment. Its objects then are briefly these—

1. To obtain the most complete Geological, Mineralogical, and Statistical knowledge possible of all the mineral resources of India, wrought or unwrought, so as to make them as publicly known as possible; to show how they have been, or are now wrought, or how they might be so to the best advantage.

2. To obtain a complete set of specimens, models, and drawings, relative to the Mining operations, Metallurgical processes, and Mineral manufactures of all kinds of India, and of Europe and America; so as to afford to the public information of every thing which can be turned to account here or in Europe, and perhaps prevent loss of time, waste of capital, and disappointment to the Indian speculator.

3. To furnish the Engineer and Architect with a complete collection of all the materials, natural or artificial, which are now, or have formerly been used for buildings, cements, roads, &c. and of all which *may* possibly be used in this department, whether European or Indian.

4. To collect for the Agriculturalist, specimens of all kinds of soils remarkable for their good or bad qualities, with the subsoil, subjacent rocks, &c. and by examination of these, to indicate their various peculiarities and the remedies for their defects.

5. To collect for Medical men, the waters of mineral springs, and mineral drugs, &c. &c.

6. And finally, by chemical examinations of all these various specimens, to determine their value, and how they may be best turned to account for the general benefit of the community.

With objects like these, the Museum of Economic Geology may be said to be placed between the purely scientific geologist and the merchant, the miner, the farmer, the manufacturer, and the builder, or in other words, the merely practical men, who may desire to know how the knowledge of the geologist and mineralogist,—to them often so recondite, and apparently so useless,—can forward their views: and its office to be, if possible, to answer all questions of this nature which may arise for public benefit.

This may sometimes be done from books, but the great library must be the collections of our Museum, which are in fact a library of examples, to which the commentary is the laboratory; where aided by the resources of the collection, questions may often be solved in an hour, a day or a week, which it would take half an *Indian* life to obtain the mere materials for investigating. An extensive collection, then, is the first requisite, and this should, if possible, comprise every inorganic product of the earth from which mankind derive any advantage, with every information relative to it. It will readily occur to the reader, that in India, owing to her infancy in some of the arts dependent on these products, as in mining, agriculture, &c.; and her singular progress in others, as in peculiar branches of Metallurgy and the like, our almost absolute ignorance of what her methods and resources are, the peculiarities of situation in which these resources may exist, those of climate, workmen, and many others, we have almost every thing yet to learn; and that to accomplish our objects we cannot be too well furnished with all the knowledge and examples of Europe and the Americas, and all those of India, or of Asia. Without these, our progress must be very limited; but in proportion as we obtain them, we may hope, without presumption, to see the day when the mines, the quarries, and the soil of India may be done justice to, which assuredly, has never yet been the case.* In this all classes are so clearly interested, that it would be superfluous to show it, as it is to show that the resources of every country, are far more readily developed with public means for investigating, preserving, and publishing all knowledge belonging to them, than where none such exist.

It is therefore hoped, that those who may be desirous of assisting this great public work, will bear in mind, that nothing, however familiar it may be to those on the spot, is indifferent to us; *for if not wanted for the institution, it may serve to procure that which is*; and the following note is given rather as a general memorandum than a specifying all which is desired. The general rule is that details cannot be too numerous, nor specimens too various, particularly if purely Indian.

* It is curious to find that upwards of 140 years ago, the ores of the precious metals were an article of export from the Dutch East Indies. This is clearly shown by the following passage from Schutter's work as translated by Hellot, and published by him under the title of "*Hellot sur les Mines*", Paris, 1753. In Vol 11. p. 285, Chap. XLVI. "*On East Indian Ores and their Fusion by the curved Furnace*," he says:—

"In 1704, Schlutter received by a private channel twenty-five quintals of ore from the East Indies, &c." And again: "These sorts of ores (of gold and silver) sent from India by the Dutch were frequently smelted at the foundery of Altenau in the Upper Hartz, but had never been smelted in the Lower Hartz. This ore was in lumps from the size of a nut to that of walnut, and by trials it was found that the quintal of 110 lbs. contained 1 oz. 8 drs. of gold and 3½ oz. of silver."

DESIDERATA FOR THE MUSEUM OF ECONOMIC GEOLOGY
OF INDIA.

I.

MINES AND MINING PRODUCTS.

1. Specimens of all crude ores, just as found. If possible also, of the rocks or matrix in which found; of those indicating the vein at the surface; of the walls of the veins; of the strata of beds passed through before reaching them; and of the rocks of the surrounding country.
2. The ores after preparation for the furnace by picking, washing, stamping, roasting, &c.
3. The rejected ores, gravel or stones found with those used; which often go under odd names, as those of "mother, devil," or the like.
4. The fluxes used, if any.
5. Memorandum of the kind of fuel used, samples of it if coal or coke, &c.; names of the trees, as bamboo, &c.; if charcoal; and if not too far, send specimens.
6. The roasted or half-smelted ore.
7. The pure metals, as obtained in a merchantable state, of all the qualities.
8. The slags, of all kinds, from the furnaces and smeltings.
9. Drawings or models, (to scale if possible) of all furnaces, machinery, and implements used in any of the processes, with drawings, plans, and models of the mine. Earthen models of the furnaces, &c. may often be well made, by the native image makers for a mere trifle.
10. Specimens of any tools used.
11. Traditions, history, and statistics of the mine or mineral products, as (1.) How and when found; (2.) Produce, gross and net; (3.) Rent if farmed, or what tax payable on the product; (4.) Price of daily labour; (5.) Amount of labour obtainable for a given price; (6.) Estimated profits, past and present; (7.) Reasons for decay or increase; (8.) What is now required to make the mine more productive; (9.) Copies or notices of any books or accounts of the mine; (10.) Health, comfort, morals, and condition of the workmen employed, average of ages, and if life among them if thought unhealthy; seasons and hours of work. Superstitious notions, peculiar diseases, &c. &c.

II.

BUILDINGS, CEMENTS, POTTERY, COLOURS, ROADS, &c.

1. Specimens from the quarries, of all kinds of building stones, useful or merely ornamental.
2. The same of limestones, shells, corals or other articles, used to make lime or cements of all kinds.

3. Specimens of the strata above and below the quarried stone.
4. Any fossil shells, bones, fish, plants, insects, or other appearances of organic remains large or small, found in or near the quarries, or amongst the rubbish and watercourses of quarried spots. If specimens appear too large to move, please to give a notice, with an eye-sketch, and estimate of the expense of moving, and preserve it till a reply is sent.
5. Specimens of the building stones or remarkable bricks used in any public edifices, monuments or tombs, with the date of their erection if known, and a note to say if exposed to weather or protected by stucco, paint, or roofs.
6. Memoranda and specimens of any plants or animals destructive to masonry, as boring worms and shells in water, and the like, with specimens of their work.
7. Ornamental or stucco-work ; specimens of it, new or old, interior or exterior, with the best account procurable of the materials, preparations, and working of them.
8. Specimens of stones and marbles, shells, &c. used for image or ornament-making ; of earths for pottery, and varnishes of coloured earths of all sorts, whether used as pigments or not.
9. Specimens of peculiarly good materials used for roads, whether ancient or modern, with prices, methods of using them, and other memoranda.
10. Prices of all the above ; rates of labour, carriage, &c. from the rough to the wrought state, and all other statistical details, as in the case of Mines and Mineral products abovementioned.

III.

AGRICULTURAL GEOLOGY.

1. Specimens of soils of good, and the best qualities, for all kinds of produce, as sugar, cotton, tobacco, &c.
2. Of infertile soils or veins of earth.
3. Of the subsoil or rock.
4. Of the stones scattered about these soils.
5. Memoranda relative to the height of these soils above the water of wells in the rains and dry seasons, and of its drainage, shelter, exposition, &c.
6. Of any kind of earths, mud, or stones used as manures, as peats from the jheels, kunkurs, &c.
7. Of the deposits (fertile and infertile) left either by the common inundations or by violent floods, with memoranda of their effects on the cultivated soil.
8. Specimens from any separate spots, where gravel or stones are collected in quantities after inundations or floods.
9. Accounts of remarkable floods, and average heights of the rise of rivers, of the raising of the soil, alterations in its produce consequent thereupon, and all other details.

10. Memoranda relative to the formation or destruction of river-banks, islands, &c. with measurement, if obtainable.

11. Samples of all kinds of efflorescent salt-earths, with specimens of the different salts prepared from them, prices of preparation, selling rates and accounts of the processes and uses of the salts.

12. Specimens of brine springs, with details of manufacture if boiled for salt, and statistics of labour and produce, &c. as in the case of mines.

IV.

MEDICAL GEOLOGY.

1. Specimens of mineral medicines of all sorts, whether produced on the spot or imported, crude and prepared, with notes and samples of the process of preparation in all its stages.

2. Of the water of mineral springs, their temperature, incrustations about them, account of their uses, and specimens of the rocks or soil in which found.

V.

NATIVE METALLURGICAL PROCESSES, OR MINERAL MANUFACTURES.

1. Exact descriptions of them, however rude or simple they may appear, with samples of the ores, fuel, fluxes, products, slags, &c.

2. Models or drawings (to scale if possible) of the furnaces and implements of all kinds; specimens of these last may be sent.

3. Memoranda and samples of the earths or sands used for moulds in castings, of the crucibles and beds, raw and baked, and of the raw material from which made.

4. Prices of raw and wrought materials.

5. Drawings of machinery used for turning, boring, polishing, &c.

In conclusion: It is not supposed that any individual, unless wholly devoted to the research, can supply the whole of the desired specimens, or even of the knowledge relative to any one product; but any *single* item of the foregoing may be of importance, at some time, to some one; and it will be the special duty of the Asiatic Society, and of the Curator of the Museum, to see justice done to every contribution; whether relating to the Geology of India in general, or to this peculiar branch of it.

(Signed)

H. PIDDINGTON,

Curator, Museum Economic Geology.

MEMORANDUM
OF
TEST FOR EXAMINATION OF CANDIDATES,
FOR THE
GREAT TRIGONOMETRICAL AND REVENUE SURVEY
Departments.

1. To write a neat legible hand.
2. A thorough knowledge of Arithmetic, but more especially of Involution, Square and Cubic Roots, Arithmetical and Geometrical Progression, Proportion or Rule of Three, Vulgar and Decimal Fractions, and Logarithmic Calculations.
3. Geometry, First 4 Books of Euclid.
4. Algebra, as far as Quadratics inclusive.
5. Elements of Plane Trigonometry.
6. Spherical Trigonometry.
7. A knowledge of Plan Drawing, or at least a proof of some degree of taste in Drawing and Printing, so as to warrant the expectation that he may turn out a good Draftsman.
8. A healthy and vigorous constitution and good eye-sight for observing.

*Form of Agreement to be taken from a Candidate prior to his admission
into the Survey Department.*

I, *A B*, do hereby agree that I will not demand my discharge for three years from the date of joining the Survey to which I am appointed and never during the Field Season. I further agree to serve in any one of the Revenue Surveys to which it may be necessary to remove me.

If against the tenor of this agreement my discharge should at any time be insisted on, I do hereby agree to repay to the Government a sum equal to one-half of the whole amount which I may have actually received in the shape of Salary or Allowance of any kind.

E. F. }
C. D. } *Witnesses.* }
Place and date.

Signature.

NOTE.—This test is applicable to both Departments, with the exception of Spherical Trigonometry, which is not required from the *Revenue Survey Candidates*.

*LATITUDES AND LONGITUDES of the Principal places in
BENGAL and NORTH-WESTERN PROVINCES. Extracted
from the Records of the G. T. Survey of India.*

District or Division.	Names of Places.	Latitude North.	Longitude East.
		° ' "	° ' "
AGRA,	Agra Taj Mahal Dome,	27 10 26	78 5 4
	Futtehpoor Sikra Dome,	27 5 35	77 42 18
	Ferozabad Station,	27 8 34	78 25 56
	Pinaht Station,	26 52 36	78 24 59
	Sikundra S. E. Minaret of Gate- way,	27 12 59	77 59 34
AJMER,	Centre of City,	26 27 10	74 43 58
ALLAHABAD, ...	Allahabad, Fort Flag Staff,	25 26 0	81 55 15
	Arial Temple,	25 25 8	81 55 29
	Badra Syud's Tomb,	25 27 16	81 57 12
	Jusi Temple,	25 26 18	81 56 44
	Kantua (Building R. B. Ganges,)	25 46 30	81 23 48
ALLYGURH, ...	Allygurh Fort,	27 55 41	78 6 13
	Baroli Station on Building,	28 5 19	78 5 57
	Hatras Station on Fort,	27 35 31	78 6 9
	Koel Mosque in City,	27 52 42	78 6 31
	Sankras Fort Station,	28 2 25	78 34 30
	Sasni Fort,	27 42 12	78 8 5
AZIMGURH, ...	Azimgurh Church,	26 3 2	83 13 20
	" Temple,	26 3 56	83 13 51
	Jagdespoor,	25 47 1	82 39 14
	Samenda,	26 0 23	83 15 57
BHAUGULPOOR, {	Mozuffurgunj Temple,	25 6 49	86 36 16
	Dolpahari Hill Temple,	25 11 53	86 41 48
BUNDLECUND, ..	Talona Hill Temple,	24 54 46	79 46 32
	Ragoli highest building in Fort,	24 44 17	79 33 34
	Rajnagar Temple,	24 53 40	79 57 9
	Rangir Station,	24 0 21	79 28 26
	Semra Fort, N. W. Tower, ...	24 14 1	79 22 14
	Saigarh Fort, highest building } N. W. ∟,	24 16 28	79 9 46
BHURTPPOOR,	Bhurtpoor Palace,	27 13 10	77 32 12

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
		° ' "	° ' "
BALASORE,	Balasore Spire,	21 30 6	86 58 11
BANCOORAH, ..	Pokranah Building,	23 25 31	87 24 46
	Ramsagur Telegraph,	23 7 0	87 19 0
	Bancoorah Telegraph,	23 14 8	87 6 31
	Bishenpoor Dome,	23 4 21	87 22 11
	Bistapoor Pagoda,	23 36 35	87 29 42
BANDA,	Kanakera, S. E. ∠ of Fort, ...	25 51 20	80 27 59
	Peprendi Station, Fort S. E. } face centre of Dome, }	25 37 39	80 26 45
BAREILLY,	Aligunj Building,	28 20 20	79 17 41
	Bareilly Buhadoor Sing's House,	28 22 9	79 26 38
	Fureedpoor Thana,	28 12 17	79 34 45
	Sisgurh Tower,	28 43 33	79 21 17
BEHAR,	Bajidpoor Telegraph,	24 43 28	84 29 58
	Baroon ditto,	24 51 35	84 15 57
	Gya Bhod Pagoda,	24 41 45	85 2 4
	Gya Ramsilla Pagoda,	24 48 44	85 3 16
	Majiaen Fort Flag,	24 19 19	83 51 48
	Saga Telegraph,	24 30 0	84 47 55
	Sherghati Fort, N. W ∠,	24 33 24	84 50 28
BENARES,	Benares Dome of Gianbapi } Musjid, }	25 18 38	83 3 12
	" Man Mundil or Hindu } Observatory, }	25 18 26	83 3 12
	" Ramnagar Stair Case,	25 16 7	83 4 1
BEERBHOOM, ...	Seori Jail,	23 54 23	87 34 14
	Serampoore Chimney,	23 50 23	87 13 19
BIJNOUR,	Afzulgurh Fort,	29 23 51	78 43 3
	Bijnour Collector's House, ...	29 22 36	78 10 32
	Chandi Hill Temple,	29 55 55	78 13 20
BOOLUNDSHU- HUR,	Boolundshuhur Building Sta- } tion, }	28 24 11	77 54 13
	Dadri Village,	28 33 13	77 35 33
	Kamona Fort,	28 7 46	78 9 14
	Malagorh Fort,	28 27 51	77 52 17
	Ramghat House,	28 5 38	78 25 46

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
		° ' "	° ' "
BHOPAL,.....	Bhopal Palace Spire,	23 15 35	77 25 56
	Chaokigurh, Upper Fort Gate- way,	23 4 51	78 6 29
	Islamnuggur House,	23 21 23	77 27 35
BUDAON,	Debrai Fort,	27 50 33	78 44 58
	Soro House,	27 53 30	78 47 20
BURDWAN,.....	Balki Tower,	23 28 1	87 39 23
	Calna Temple,	23 13 17	88 24 33
	Gunjua Tower,	22 58 30	87 36 2
	Mahdipur Tower,	23 9 56	87 47 4
CAWNPOOR, ...	Cawnpoor Christ Church,	26 28 15	80 23 45
	Suvada,	26 26 6	80 24 12
CUTTACK,	Lall Bagh or Commissioner's House,	20 27 35	85 53 51
	Barabati Fort Flag Staff,	20 28 54	85 54 15
DEHRA DOON,	Dehra or Gurudwara Temple, ...	30 18 58	78 4 27
	Nalapani or Kalingar Fort, ...	30 20 27	78 8 26
	Rajpur Dak Bungalow,	30 23 50	78 8 25
	Timli Village Temple,	30 22 19	77 45 51
DEHLI,	Dehli Jumma Musjid Dome, ...	28 38 58	77 16 30
	Kootub Minar,	28 31 23	77 13 39
DINAJEPOOR, ...	Dinajepoor Mr. Grant's House,...	25 36 34	88 40 12
DHOLPOOR TER- RITORY,	Machkanda highest Building, ...	26 41 1	77 54 38
	Munia Village Mosque,	26 49 16	77 57 45
	Pachgaon Building,	26 43 2	77 53 15
ETAWAH,	Bareh Fort,	26 29 59	79 17 24
	Etawah Old Fort,	26 45 31	79 3 18
	Sabad Fort Bastion,	26 51 37	79 34 24
	Usrari Fort Building,	26 33 39	79 37 12
	Yani Fort,	26 27 36	79 23 10
FURBUCKABAD,	Agosi Fort,	26 56 40	79 43 59
	Chibra Mao Thana,	27 8 53	79 32 9
	Kudrel Fort Building,	26 54 13	79 21 47
	Nuwabgunj Thana,	27 26 6	79 26 45
	Amoher Fort,	27 1 43	79 44 54
	Jankat Fort,	26 51 25	79 54 5

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
		° ' "	° ' "
FUTTEHPOOR, ..	Jahanabad,	26 6 2	80 24 18
	Musapur Tower,	25 46 33	80 40 47
GHAZEEPOOR, ..	Ghazeepeer Church,	25 33 36	83 35 13
	Lord Cornwallis' Monument,	25 33 30	83 35 19
	New Burial Ground,	25 33 6	83 34 32
	Opium Agent's House Signal Staff,	25 34 25	83 37 9
	Roman Catholic Chapel,	25 33 43	83 35 20
	Old Fort, Sri Narain Roy's } House, }	25 34 48	83 38 4
GOORGAON,	Firozpoor Palace,	27 47 8	76 59 41
	Hodul Building,	27 53 24	77 24 35
GORUCKPOOR, ..	Goruckpoor Rajghat Temple, ...	26 44 8	83 23 44
	" Mosque near Rajghat,	26 44 27	83 23 37
	Mahamadpur,	26 46 27	83 9 16
	Nandaor,	26 56 37	83 6 57
	Rajabari,	26 54 1	83 18 2
GWAJIOR TERRITORY,	Bheelsa Temple,	23 31 35	77 50 39
	Gwalior Hill Temple,	26 13 10	78 12 28
	Isagurh Fort,	24 50 3	77 55 43
	Kalianpur Observatory,	24 7 12	77 41 45
	Narwar Hill Fort,	25 39 2	77 56 57
	Satalgarh Hill Fort, Dome,	24 6 23	77 43 37
	Satalgarh Hill Fort, Dome,	26 14 26	77 26 58
HUMERPOOR, ..	Badek Pillar on Jumna, R	26 22 19	79 31 50
	Kalpi Fort Temple,	26 7 49	79 47 22
	Pal: Village House,	26 14 45	79 38 48
HOOGHLY,	Chinsurah College,	22 53 24	88 26 34
	Fort Gloucester Highest Chim- } ney, }	22 29 27	88 12 58
	Nibria Tower,	22 35 37	88 17 10
	Pondua Dargah Spire,	23 4 28	88 19 43
	Serampore Church,	22 45 26	88 23 10
HIJELLE,	Natsal Village,	22 12 4	88 5 21

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
		° / "	° / "
JALOUN, BUN- DLEKUND, ...	Jagamanpoor Fort,	26 24 15	79 15 23
	Jaloun Temple,	26 8 32	79 22 42
	Kotra Temple,	25 48 25	79 21 5
	Maheva highest Building,	26 7 28	79 39 50
	Parasan Temple,	25 56 15	79 43 52
JOUNPOOR,	Badshapur Flag on Tree,	25 39 41	82 14 17
	Jounpoor Church, N. W. Spire,	25 43 48	82 44 7
	" Fort S. W. Bastion,	25 44 53	82 43 49
	" Jail N. W. Bastion,	25 44 23	82 43 56
	" Musjid N. Spire of Gate- way,	25 45 31	82 43 38
KUMAON,	Almorah Commissioner's House,	29 35 10	79 41 16
MUTHRA,	Aring Building Station,	27 29 3	77 34 11
	Awa Chimney,	27 27 2	78 31 47
	Daigaon Building,	27 49 51	77 24 57
	Dig Temple,	27 28 42	77 22 3
	Muthra City Building,	27 30 13	77 43 45
	Noh Tower,	27 50 49	77 41 13
MOZUFFERNUG- GUR,	Baseda Fort Bastion,	29 33 15	77 53 38
	Gohdna Tower Hill Station,	29 37 13	77 56 30
	Kaliana Observatory,	29 30 49	77 41 33
MEERUTH,	Hapur Station on Building	28 43 20	77 49 33
	Meeruth Church Steeple,	29 0 41	77 45 3
	Pirghyl Building,	28 40 30	77 15 19
	Salawa Byragi's Mut,	29 13 46	77 42 12
	Sirdhana Begum's Palace,	29 9 6	77 39 26
	Sirdhana Church Steeple,	29 8 47	77 39 32
MIDNAPOOR, ...	Gop Tower,	22 25 13	87 19 25
	Midnapoor Park House,	22 24 48	87 21 12
	Midnapoor Nazargunj House,	22 24 17	87 21 18
MALDA,	Alsapur,	24 44 22	88 23 28
	Onal,	24 59 56	88 18 49
MIRZAPOOR, ...	Chunar Fort Flag Staff,	25 7 30	82 55 1
	Mirzapoor Cantonment,	25 10 55	82 38 15
	Mirzapoor Court House or Ka- cheri,	25 9 19	82 37 23

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
		o ' "	o ' "
MOORSLEDABAD, {	Berhampoor Hospital Station, ...	24 6 7	88 17 33
	Bagdhamari Indigo Factory, } building South of Ganges, ... }	24 21 16	88 23 53
MORADABAD, ... {	Agwanpoor Fort,	28 55 43	78 45 57
	Kasipur highest Turret,	29 12 49	78 59 46
MONGHYE,	Jurgaon,	25 27 26	86 43 38
MYNPOOREE, ... {	Kasmaro Fort,	27 6 32	79 19 41
	Laigas Fort Bastion,	26 58 30	79 21 52
	Saman Fort,	27 1 24	79 13 58
	Samsergunj Fort Bastion,	27 0 9	79 22 13
	Saonasi Fort,	27 3 43	79 20 11
	Sakit Temple,	27 26 7	78 49 15
NUDDEA, ... {	Goa Ghat,	23 51 10	88 29 59
	Kishnagar E. Jao Tree,	23 23 31	88 30 58
	Maisgunj Factory,	23 25 11	88 26 54
	Santipur Black Temple,	23 14 24	88 29 6
	Sukria Temple,	23 7 59	88 29 11
OUDE, {	Lucknow Begum's Mausoleum,	26 51 8	80 57 59
	" Gazi Uddin Hyder's } Mausoleum, }	26 51 27	80 59 19
	" Mote Mahal Palace, ...	26 51 22	80 58 57
	" Observatory Transit } Telescope, }	26 51 10	80 58 57
	Gumsira Musjid,	25 43 43	81 26 1
	Sora Temple in Village,	26 17 31	81 15 0
PANEEPUT, {	Kurnal Church Steeple,	29 42 17	77 1 45
	Kurnal City Bunnia's House, ...	29 40 45	77 1 56
PATNA, {	Dinapoor Flag Staff,	25 38 20	85 5 09
	Dumri Fort S. E. ∠	24 34 57	84 21 36
	Patna Gola,	25 37 12	85 10 57
PACHEET, OR JUNGLE ME- HALS, {	Chas Bungalow,	23 38 10	86 12 32
	Khatras Temple,	23 48 51	86 20 32
	Raganathpoor Telegraph,	23 31 31	86 42 32
PILLIBHEET, ... {	Kalianpoor Station on mound } close West of Village, }	28 35 7	79 47 1
	Tanra Thanah Flag,	29 4 17	79 28 15

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
		° ' "	° ' "
PURNEEA,	Banghora Tower,	26 13 20	87 34 32
	Dewangunj Tower,	26 16 53	86 56 47
	Ramgunj, Base East Tower,	26 18 59	88 19 56
	Ramnagar Tower,	26 2 12	87 4 3
	Sonakhoda, Base West Tower, ...	26 15 25	88 14 30
RAJSHAHEE, ...	Karchaka Indigo Factory,	24 22 11	88 30 36
	Rampoore Bauliah Judge's Ku- cherry,	24 21 46	88 37 45
RAMGHUR,	Palgunj Temple,	24 4 48	86 15 34
	Parasnath Highest Temple, ...	23 57 50	86 10 17
	Ramgurh Fort,	23 38 22	85 34 5
	Serampoore Building,	24 7 17	86 22 46
SHAHJEHAN- POOR,	Julalabad Fort,	27 43 20	79 41 53
	Khera Bajera Mound,	28 1 35	79 35 11
SIMLA,	Simla Church,	31 6 13	77 12 49
	Simla Magnetic Observatory,	31 6 6	77 11 1
SUHARUNPOOR, {	Chosana Building,	29 39 58	77 13 14
	Gaoghar centre Dome,	29 36 2	77 29 7
	Hurdwar Raja's House, ...	29 57 30	78 12 52
	Kutubgarh Haveylee,	29 33 23	77 28 58
	Lohari Mosque,	29 35 45	77 31 9
	Nojhili Tower Station,	29 53 22	77 42 52
	Sikar Temple,	29 45 37	77 58 1
Sirsawa Building,	30 0 53	77 26 20	
SHAHABAD, ...	Bamani Telegraph,	24 56 40	84 7 50
	Rotasgurh Building,	24 37 38	83 59 17
SAUGOR AND NEBBADA TER- RITORIES, ...	Baitul Fort, S. E. angle,	21 51 13	77 58 15
	Husingabad Fort,	22 45 43	77 45 5
	" Temple,	22 45 42	77 45 30
	Jagdhur Hill Station,	21 49 39	78 0 58
	Jubbulpore Magistrate's House,	23 9 39	79 59 43
	Kherla Hill Fort, N. E. ∠, ...	21 55 42	77 59 33
	Morpani Hill Station,	22 29 40	77 56 12
	Nowgong (Bundelas States,) ...	25 3 30	79 31 0
	Saugor Magazine in the Fort, ...	23 50 9	78 46 51
Sera Fort, S. E. ∠,	21 48 35	77 56 9	

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
		o / "	o / "
SARUN,	Baila Temple,	27 9 9	84 21 24
	Bettia Rajah's House,	26 48 8	84 32 39
	Mooteharry Collector's Kutchery,	26 39 46	84 57 29
	Mullye Burial Ground,	26 45 27	85 29 12
	Narkatia Indigo Factory,	26 39 50	85 26 25
	Ramnagar Rajah's House,	27 9 53	84 22 2
	Rutwul Town,	27 0 58	84 14 1
	Segowli Temple,	26 46 41	84 47 51
TIRHOOT,	Boolakipoor Tower,	26 40 54	85 28 57
	Ghosath Tower,	26 17 23	85 19 27
	Mirzapoor Tower,	26 31 3	86 19 3
	Narhar Tower,	26 31 47	86 8 36
	Pota oorf Tajpoor Tower,	26 22 39	85 28 46
	Paladpoor Station,	26 4 20	85 29 39
24-PURGUN- NAHS,.....	Akra Semaphore,	22 30 26	88 17 36
	Base Line N. Tower,	22 42 35	88 25 4
	Ditto S. Tower,	22 36 59	88 25 22
	Bood Semaphore,	22 22 31	88 9 4
	Calcutta Observatory No. 35, } Park Street, }	22 33 1	88 23 59
	Dum-Dum Monument,	22 37 53	88 24 36
	Diamond Harbour Semaphore,...	22 11 11	88 13 47
	Flag Staff, Fort William,	22 33 35	88 22 43
	Govt. House Dome,	22 34 2	88 23 59
	Hooghly Semaphore,	22 12 39	88 3 41
	Moyapoor Semaphore,	22 26 15	88 10 52
Shampoer Semaphore,	22 29 23	88 14 24	

LATITUDES AND LONGITUDES of the principal places in the MADRAS PRESIDENCY, Extracted from the Records of the Great Trigonometrical Survey of India.

District or Division.	Names of Places.	Latitude North.	Longitude East.
		° / ' "	° / ' "
BARAMAHL, ...	Hurroure Fort,	12 2 53	78 31 33
	Kistnagherry Flag Staff,	12 32 19	78 15 27
	Pennagra Fort,	12 7 48	77 56 39
	Ryascottah Flag Staff,	12 31 20	78 4 44
	Tengricotta Fort,	12 0 47	78 26 20
CANARA, ...	Ankola Musjid, near the Sea,	14 39 43	74 20 58
	Honour Bungalow,	14 16 36	74 29 4
	Koondapoor Flag Staff,	13 38 13	74 43 48
	Mirjan Fort, S. E. Angle,	14 29 16	74 27 33
	Sadashevaghur Droog Flag Staff,	14 50 45	74 10 21
CARNATIC, ...	Arcot Fort, Nabob's House, } S. W. ∠,	12 54 16	79 22 31
	Arnee Monument,	12 40 23	79 19 31
	Calastree Hill Pagoda,	13 45 19	79 44 34
	Chillumbrum Pagoda,	11 24 9	79 44 7
	Chinglepet Fort Flag Staff,	12 42 1	80 1 13
	Chittepet Mosque,	12 27 59	79 23 30
	Cuddalore Flag Staff,	11 43 24	79 49 6
	Gingee Droog,	12 15 19	79 26 8
	Madras Observatory,	13 4 11	80 17 21
	Mowbray's House Cupala,	13 1 33	80 17 21
	Pondicherry Flag Staff,	11 55 57	79 52 33
	Porto Novo Flag Staff,	11 29 25	79 48 13
	Pullicate Church,	13 25 8	80 21 24
	Trinomally Pagoda,	12 13 56	79 6 43
	Vellore Fort Pagoda,	12 55 7	79 10 42
Verdachillum highest Pagoda,	11 31 4	79 21 39	
CEDED DIS- TRICT,	Bellary Flag Staff,	15 8 57	76 57 10
	Chennumpilly Droog Redoubt,	15 18 12	77 38 11
	Cuddapah Fort Mosque,	14 28 49	78 51 47
	Cumbum Fort, N. E. Angle,	15 34 15	79 9 1
	Durmahverum, or Darmavaram, } Fort Building,	14 24 35	77 45 50
	Goorumcondah Building,	13 46 20	78 37 49
	Gooty Droog Flag Staff,	15 6 53	77 41 32
	Hundee Anantapoor Fort, S.W. ∠	14 40 58	77 39 0
	Koil Koil Koontlah Fort highest } Cavalier,	15 13 57	78 21 28
	Kurnool Fort Laul Battery,	15 49 58	78 5 29
	Nauguldianny Fort, S. W. ∠,	15 55 0	77 36 14

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
CEDED DISTRICT,	Poolavaindla Pagoda,	14 24 59	78 15 6
	Poremaumla Fort, S. W. ∟, ...	15 0 45	79 1 54
	Punganoor Palace,	13 21 39	78 36 33
	Rachootee Fort Pagoda,	14 3 44	78 47 30
	Sidout Fort, S. E. angle,	14 27 56	79 0 40
	Todmurry Fort Centre Cavalier, ...	14 33 47	77 53 50
	Wudjar Curior Fort,	15 1 44	77 25 34
COCHIN, ...	Chitwa Bungalow,	10 32 6	76 4 23
	Cochin Flag Staff,	9 58 7	76 17 0
COIMBETOO, ...	Allambaddy Fort,	12 8 38	77 47 14
	Coimbetoor Palace,	10 59 41	76 59 46
	Darapooram Fort Cavalier,	10 44 35	77 34 28
	Erode Fort, S. E. Cavalier,	11 20 29	77 46 3
	Kurroor Pagoda,	10 57 42	78 7 16
	Pyney Hill Pagoda,	10 26 23	77 33 42
CORG, ...	Veer Rajenderpett Hill Tree, ...	12 12 34	75 51 6
GANJAM,	Ganjam Two Storied House, ...	19 22 27	85 2 52
GOA, ...	Anjadeepa Flag Staff,	14 45 36	74 9 3
	Cabo de Rama Tower, or Cape } Ramas,	15 5 12	73 57 27
	Murmagaon Flag Staff,	15 24 33	73 49 56
	Rachol College, front of the } Church,	15 18 34	74 2 31
GUNTOOR, ...	Chintapilly Fort Building,	16 41 22	80 10 58
	Condapilly Droog Pagoda,	16 37 59	80 34 17
	Guntoor Mosque,	16 17 42	80 29 0
	Innacondah Hill Pagoda,	16 3 13	79 46 15
	Nundygamah Pagoda,	16 46 37	80 19 41
	Ummaravutty Pagoda,	16 34 55	80 24 2
HYDRABAD, OR THE NIZAM'S DOMINIONS, ...	Alangaon Fort S. W. Angle,	20 56 37	77 40 42
	Ambla Fort,	20 10 14	77 50 18
	Arambi Fort, S. E. Angle,	20 9 10	77 52 32
	Arjunooz Hill Pagoda,	18 29 33	74 42 3
	Arri Hill Pagoda,	18 20 8	76 51 49
	Ashti Fort, Highest Bastion,	21 3 14	77 41 7
	Ashagaon Peak,	18 17 6	76 40 10
	Awsa Hill Musjid,	18 13 23	76 33 41
	Badgaon Fort, S. E. Angle,	20 14 43	77 59 10

LATITUDES AND LONGITUDES.—(Continued.)

District or Divison.	Names of Places.	Latitude North.	Longitude East.
		° ' "	° ' "
	Balapur Fort, S. W. ∟,	18 53 13	77 54 14
	Balki Palace,	18 2 34	77 15 5
	Batumbra Palace,	18 4 10	77 12 10
	Bhavani Hill Pagoda,	19 30 24	77 50 6
	Bider Base East End,	17 53 32	77 39 27
	Bider Base West End,	17 57 33	77 33 38
	Birkur Palace,	18 27 45	77 50 25
	Bidar Minaret,	17 54 49	77 34 21
	Boral Hill Pagoda,	17 54 48	77 7 11
	Chalkapur Hill Pagoda,	17 53 18	77 18 23
	Chini Maligaon Temple,	18 24 30	77 34 42
	Damargida Observatory,	18 3 16	77 42 31
	Dharasin Hill Pagoda,	18 10 32	76 2 52
	" white Tomb,	18 10 16	76 4 54
	Dhoki Eedgah,	18 22 23	76 8 25
	Digres Fort, S. E. Bastion,	20 6 5	77 45 29
	Dongargaon Hill Pagoda,	18 16 54	77 22 28
	Gawargaon Durga,	18 25 42	76 11 46
	Halburga Hill Pagoda,	17 58 38	77 19 52
	Hyderabad Mecca Musjid,	17 21 41	78 29 45
	" Residency House,	17 23 6	78 30 32
	" Residency Flag Staff,	17 23 14	78 30 33
	" Raymond's Tomb,	17 21 57	78 32 16
	Itoli Pagoda on Hill,	18 59 38	77 58 54
	Kadmuli Peak,	18 31 24	76 53 29
	Kurbur Sevali Hill Pagoda,	18 49 1	77 45 11
	Kutuphul Hill Pagoda,	17 33 30	75 4 12
	Latur Eedgah,	18 24 9	76 37 13
	Maliabet Hill Pagoda,	18 29 31	77 3 35
	Mamdapur Tomb,	18 17 47	76 59 53
	Manba Building,	20 30 35	77 40 26
	Meduk Drug Mosque,	18 2 36	78 17 49
	Mudhal White Pagoda,	18 13 17	77 21 28
	Mysgaon Hill Pagoda,	18 6 35	75 31 10
	Nimba Fort N. E. Bastion,	20 55 12	77 40 19
	Rahir Pagoda,	18 53 38	77 42 41
	Sangwi Hill Pagoda,	18 24 13	76 56 47
	Sekunderabad Cenotaph,	17 26 40	78 31 28
	" Church,	17 26 38	78 31 44
	Toramba Pagoda,	17 56 16	76 29 43
	Torna Pagoda,	18 13 51	77 18 21
	Tuljapur Durga,	18 0 36	76 5 33
	" Eedgah,	18 0 31	76 6 20
	Udghir Musjid,	18 23 17	77 8 34
	Umankher Hill Pagoda,	19 36 25	77 43 55

HYDRABAD, OR
THE NIZAM'S
DOMINIONS,...

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
		° ' "	° ' "
MADURA, ...	Dindigal Flag Staff,	10 21 39	78 0 17
	Madura, N. E. Pagoda,	9 55 16	78 9 44
	Ramagherry Hill Palace,	10 38 18	78 9 47
MAHRATTA, ...	Annagoondy Building,	15 21 6	76 31 59
	Oonchicuttae Fort S. E. Angle,	15 8 5	75 4 10
	Singatoor Fort, S. E. ∠,	15 3 27	75 55 48
	Soondoor Fort, S. W. ∠,	15 5 42	76 35 41
	Streemuntagud Pagoda,	15 6 53	75 39 6
	Watunhully Round Tower,	14 52 40	75 14 9
MALABAR, ...	Angadipooram Judge's House, ...	10 58 32	76 16 2
	Baekul Fort Cavalier,	12 23 33	75 4 29
	Baypoor Saw Mill,	11 10 3	75 50 44
	Calicut Flag Staff,	11 15 9	75 48 48
	Cannanore Flag Staff,	11 51 12	75 24 44
	Mangalore Flag Staff,	12 51 40	74 52 36
	Palghatcherry Fort S. W. ∠, .	10 45 49	76 41 48
	Soobramanee Old Pagoda,	12 39 47	75 43 41
	Tellicherry Flag Staff,	11 44 53	75 31 38
MASULIPATAM,	Masulipatam Flag Staff,	16 9 8	81 11 38
MYSORE,	Bangalore Palace,	12 57 37	77 36 56
	Bellore Fort Pagoda,	12 59 1	76 46 20
	Chinneroyputtun Fort,	12 54 12	76 25 55
	Chittle Droog Flag Staff,	14 13 8	76 26 15
	Hassun Fort,	13 0 16	76 8 8
	Holekurrae Fort Pagoda,	14 2 47	76 13 36
	Kopa Droog,	13 32 4	75 21 51
	Kowlae Droog Muntapum,	13 43 9	75 9 30
	Mailcottah Hill Pagoda,	12 40 35	76 41 38
	Mysore Fort Centre Cavalier,...	12 18 24	76 41 48
	Nuggur or Biddenoor Flag Staff,	13 49 12	75 4 31
	Nundy Droog Station,	13 22 17	77 43 38
	Paughur Droog Station,	14 6 23	77 19 8
	Serah Flag Staff,	13 44 43	76 57 16
Seringapatam Fort Pagoda, ...	12 25 33	76 43 8	
	Shevagunga Pagoda,	13 10. 12	77 15 51
NELLORE,	Adtenki, S. E. corner of the } ruined Fort, }	15 48 42	80 0 52
	Nellore Pagoda,	14 28 1	80 1 40
	Oodagherry Droog Station, ...	14 51 56	79 19 5

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Place.	Latitude North.	Longitude East.
		° ' "	° ' "
NELLORE,	Pelloor Fort, N. W. Angle,	15 27 27	80 5 29
	Poudella Pagoda,	15 36 34	79 39 36
	Venkettygherry Pagoda,	13 57 12	79 37 19
RAMNAD,	Ramisseram Sand Hill Pagoda,	9 18 7	79 20 56
	Ramnad Fort, Palace Tower, ...	9 22 16	78 52 9
SALEM,	Namcul Droog, Fakeer's Flag,	11 13 24	78 12 26
	Salem (Perria) Fort, S. W. Z	11 39 10	78 11 47
	Sankerry Droog Station,	11 28 52	77 53 58
	Womooloor Fort, Highest Ca- valier,	11 44 10	78 4 49
TANJORE,	Nagore Flag Staff,	10 49 26	79 53 24
	Negapatam Flaff Staff,	10 45 37	79 53 28
	Tanjore Great Pagoda,	10 47 0	79 10 24
	Tranquebar Tower,	11 1 37	79 53 44
TINNEVELLY, ...	Palamcottah Flag Staff,	8 43 32	77 46 43
	Tinnevelly Highest Pagoda, ...	8 43 47	77 43 49
	Tutacorin Flag Staff,	8 48 3	78 1 27
TONDIMAN, ...	Tirmium Hill Fort Tree,	10 14 54	78 47 37
TRAVANCORE, .	Oodagherry Flag Staff,	8 14 37	77 22 49
	Quilon Flag Staff,	8 53 28	76 36 59
	Trivanderam Great Pagoda, ...	8 29 3	76 59 9
TRITCHINOPOLY,	Tritchinpoly Rock Station on } Pagoda, }	10 49 45	78 44 21
	Trivellary Rock Pagoda,	10 57 26	78 42 33

LATITUDES AND LONGITUDES of the principal places in the BOMBAY PRESIDENCY, Extracted from the Records of the Great Trigonometrical Survey of India.

District or Division.	Names of Places.	Latitude North.	Longitude East.
AHMEDNAGAR COLLECTORATE,	Alsunda Hill Pagoda,	18 29 15	75 3 14
	Chanda Hill Pagoda,	18 38 49	74 57 32
	KaIsubai ditto ditto,... ..	19 36 0	73 45 2
	Kothul ditto ditto,	18 46 36	74 45 57
	Phalsi ditto ditto,	19 20 52	74 30 39
	Rasin Pagoda,... ..	18 26 5	74 57 47
	Wandew Hill Pagoda,	18 46 27	74 48 33
BOMBAY ISLAND,	Bombay Observatory,	18 53 45	72 51 14
	" Light-house,	18 53 40	72 51 10
	" St. Thomas' Cathedral,	18 55 50	72 52 30
	" Baykala Church,	18 58 5	72 52 23
	" Butcher's Island Tower,	18 57 31	72 56 41
KOLAPUR STATE,	Bhowra Fort Musjid,... ..	16 32 37	73 51 27
	Phonda Ghaut S. Peak,	16 15 3	73 57 40
	Salva Hill Fort W. end,	16 27 24	73 45 46
	Talia conical Peak,	16 28 28	73 55 31
	Walwan Mound,	16 25 6	73 54 22
NORTH CONKAN COLLECTORATE,	Karnala Peak highest Point,	18 52 49	73 9 35
	Malangar Peak,	19 6 29	73 13 7
	Shiw Fort Flag Staff,	19 2 43	72 54 32
	Uran Hill Pagoda,	18 54 1	72 57 59
POONA COLLECTORATE,	Bhawra Hill Pagoda,	17 57 53	74 59 32
	Bholeshwar Hill Pagoda,	18 26 5	74 16 58
	Dhonda Pagoda,	18 27 57	74 37 43
	Gangarh Rock,	18 31 34	73 24 41
	Kondapur Pagoda,	18 43 36	74 14 38
	Lohogaon Hill Pagoda,	18 37 6	73 57 45
	Nighoj Hill Pagoda,	18 44 35	73 51 56
	Parvati Hill N. Pagoda,	18 29 47	73 53 19
	Patas Hill Pagoda,	18 25 55	74 32 25
	Poona Observatory,	18 30 41	73 55 21
	" St. Mary's Church,	18 30 23	73 55 33
	" Chinchwar Pagoda,... ..	18 37 19	73 48 32
	" Lowla Hill Pagoda,	18 31 18	73 44 40
	" Phursangi Pagoda,... ..	18 28 23	74 1 9
" Bapdew Ghat ditto,	18 24 26	73 56 55	
" Singarh Fort,	18 21 52	73 47 46	
	Purandhar Hill Pagoda,	18 16 33	74 0 45

LATITUDES AND LONGITUDES.—(Continued.)

District or Division,	Names of Places.	Latitude North.	Longitude East.
		° ' "	° ' "
PORTUGUESE TERRITORY,	Agoda Fort,	15 29 29	73 48 56
	" Light-house,	15 29 26	73 48 57
	" St. Lorenzo's Church,	15 29 32	73 49 24
	Narwar Church,	15 35 23	74 21 17
PUNT SACHIN,	Lingana Hill Fort,	18 15 7	73 32 38
	Rajgarh House in Fort,	18 14 40	73 43 26
	Tikona Fort,	18 37 50	73 33 15
	Torna Fort Hill Station,	18 16 26	73 39 47
	" Rock,	18 15 58	73 39 19
	" Peak,	18 15 57	73 39 7
	Tung Fort Pagoda,	18 39 30	73 30 19
RATNAGHIRI COLLECTORATE,	Adhur Hill Pagoda,	17 24 11	73 12 41
	Bala Pir,	17 34 48	73 17 51
	Chambardrug Peak,	17 58 17	73 18 19
	Fort Victoria,	17 58 19	73 5 1
	Makrangarh W. Fort Bush,	17 50 56	73 38 20
	" E. Fort Centre,	17 50 53	73 38 47
	Mumbri Hill,	16 21 27	73 24 44
	Rari Fort N. Bastion,	15 45 7	73 42 25
	Ratnaghiri Fort,	16 59 42	73 18 43
	Shomwarghar Hill Fort,	17 48 26	73 33 11
	Sirgaon Highest Point,	17 57 27	73 23 31
	Sideswar Fort Highest Point } E. end, }	16 7 57	73 55 15
	Vingorla Signal,	15 51 14	73 39 24
	Waloli Centre Rock,	15 59 24	73 38 26
SCINDIA'S TERRITORY, ...	Moreshwar Pagoda,	18 26 35	74 46 5
	Pergaon Pagoda,	18 30 38	74 44 56
SATTARA STATE,	Kumbaghat Peak,	18 22 11	73 27 38
	Mahadeo Hill Pagoda,	17 51 7	74 41 29
	Pali Hill,	17 35 18	73 46 4
	Partabghar Hill Fort Tree,	17 56 6	73 37 10
	Sulki Hill Pagoda,	17 45 41	74 55 52
SAWUNTWAREE,	Hanmantghur Conical Point W. } end of Fort, }	15 51 12	74 0 23
	Mangaon S. Peak,	15 56 47	73 50 9

LATITUDES AND LONGITUDES.—(Continued.)

District or Division.	Names of Places.	Latitude North.	Longitude East.
		° ' "	° ' "
SHOLAPUR COL- LECTORATE, ...	Kalam Peak North,	18 22 31	75 48 20
	" " South,	18 22 28	75 48 16
	Karki Hill Pagoda,	17 45 51	76 4 30
	Kem ditto ditto,	18 11 9	75 18 50
	Karmala Pagoda,	18 24 13	75 15 4
	Mhaisgaon Hill Pagoda,	18 6 35	75 31 0
	Wairag Pagoda,	18 3 42	75 50 45
	Wardal Tomb,	17 52 9	75 54 35
TANNA COL- LECTORATE, ...	Raigarh Palace S. end of Fort,	18 13 59	73 29 8
	" Hill Pagoda in Fort,	18 14 8	73 29 20
	Sir Sidney Beckwith's Monu- ment Mahbleshwur Hills, ... }	17 55 25	73 42 7

NOTE.—The Latitudes given in these Tables are derived from independent Astronomical Observations made at the following stations :

	Latitude.	Longitude.
	° ' "	° ' "
Punnes Station,	8 9 33	77 39 42
Dodagoontah ditto,	12 59 53	77 39 41
Damargida ditto,	18 3 16	77 42 31
Kalianpur ditto,	24 7 12	77 41 45
Kaliana ditto,	29 30 49	77 41 33

On the other hand the Longitudes recorded in the Tables are all deduced from Computations, taking that of the Madras Observatory as the origin of the deductive process. The value of this fundamental element as used in the Computations of the Great Trigonometrical Survey is as follows :

Longitude of the Madras Obser- } ° ' ' { Determined from Captain War-
vatory East of Greenwich, ... } 80 17 21 { ren's Observations.

In the Tables of Latitudes and Longitudes of the Great Trigonometrical Survey Stations, given in the Lithographed Revenue Survey Maps, the Longitudes used are called "corrected Longitudes" because they are Great Trigonometrical Survey values diminished by 0° 3' 25." This correction has been applied with the view of referring those elements to the Longitude of the Madras Observatory (80° 13' 56") as subsequently adopted by the Board of Admiralty, and the Royal Astronomical Society of London, but in the foregoing Tables, the Longitudes recorded are *uncorrected* elements.